A Design Framework for Collective Inquiry Learning Environments

by

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Ontario Institute for Studies in Education
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Abstract

This thesis describes a design-based research study of a recent KCI implementation in a whole-class inquiry elementary science curriculum called WallCology, focusing on the interaction design aspects of its technological support. From that, the thesis builds a framework for HCI design for the specific context of Knowledge Community and Inquiry (KCI), a CSCL model that guides the design of collective inquiry curriculum in which students work together to advance their collective progress on a set of well-defined learning goals. This design framework comprises a series of conceptual design principles, guidelines for implementing a visual language for interface design, and an ontology of human-computer interactions that could emerge in a KCI enactment, with examples of GUI design solutions to support them.
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Chapter 1
Introduction

Increasingly, technology environments are making their way into educational settings, including K12 and university classrooms, online learning, lifelong and other informal learning contexts. Often, as in the case of MOOCs, Khan Academy, or YouTube, the design of these environments (i.e., their presentation or interactive element) is presented to teachers and learners as simply expedient, incidental or irrelevant to learning. However, in educational research, there is a strong emphasis on the design of technology environments for learning (e.g., Quintana et al, 2004), which are seen as deeply connected, often tailored to specific forms of learning and interaction. When describing the development of a new open source technology platform for learning environments, Slotta and Aleahmad (2009) argued that:

Rather than remaining a consumer of e-learning systems, educational research must take a front seat in driving the design of new systems, posing interesting questions about the nature of learning and instruction, and investigating new forms of curriculum, new interactions between students, and new roles for the instructor (p. 170).

This thesis helps respond to that provocation by offering a design framework that supports educational researchers who face an increasingly complex and expansive landscape of options for functionality that could support their investigations. For the specific research community engaged in Computer Supported Collaborative Learning (CSCL), this growing complexity translates into a richer and more varied repertoire, but also into the challenge of mastering, understanding, and evaluating an ever-increasing variety of techniques, methodologies, and resources. Teachers and practitioners face a growing diversity of proposals and ideas that deserve to be considered before being able to judge which is best suited to the specific demands and characteristics of their practice. In general, learning designers must navigate a broad and open field, lavish with innovation opportunities, but still devoid of standards that signal directions and paths of proven efficiency. Researchers find, in this wide variety of models and approaches, an abundance of interesting questions and research objects, but also a profusion of variables and interactions, which presents a persistent challenge to the community.
Considering that CSCL is a pedagogical approach that depends directly and intrinsically on technology-mediated materials, activities and interactions, it is safe to conjecture that the domain of Human-Computer Interaction (HCI) is instrumental to its progress. In HCI, the notion of Graphical User Interfaces (GUI) has come to play a central role. Although new technologies are allowing the introduction of haptic, speech, and other nontraditional interfaces, GUI remains the predominant form of interaction between people and computers (Kortum, 2008). Thus, it is reasonable to assume that concern for the quality of GUI design would be central to any CSCL research. However, the design of GUI remains an area where CSCL researchers continue to experience significant challenges. What constitutes an effective user interface? How can we know for sure? What are the best practices or design approaches that can ensure effective, engaging interfaces? Most researchers do not have clear responses to such questions, and lack systematic approaches or frameworks for interface design.

Educational Modeling Languages (EML) such as IMS Learning Design (IMS-LD) have been developed to ensure consistency and interoperability. While these languages do provide frameworks for Technology Enhanced Learning (TEL) designs, they are offered at a low level of abstraction and tend to take for granted the robustness of HCI design. For example, a learning designer who uses the IMS-LD specification will find support to determine, for example, that their design should include an area for comments to provide an asynchronous means of communication amongst learners, but would not find any guidance on the specific interface design of such a component (i.e., its specific placement, look and feel, size, etc). Other standards have been offered in the form of interoperability architectures for e-learning contents such as SCORM (Bohl et al., 2002) and GLUE!-PS (Prieto et al., 2011), supporting the integration of learning designs within Learning Management Systems (LMS), such as Moodle. While useful for accelerating and standardizing programming and development of learning environments, these solutions also fail to support user interface design, focusing on connecting the content designed by educators to the pre-existing interfaces of LMSs.

The lack of specific support for HCI design in the context of CSCL research may have resulted in the general neglect of this aspect of the research projects. This is somewhat ironic, given the emphasis of CSCL on the scaffolding role of technologies, and may have some important consequences. Design flaws in the interface, such as usability issues or ill structured information hierarchies, could have a direct and significant impact on the outcome of the learning process.
Also, aesthetic aspects such as colors, typography and iconography, whose importance is often undervalued, can alter the learner's emotional disposition towards the learning environment or materials, with consequences for the cognitive processes or outcomes (Ashby, Isen, & Turken, 1999; Norman, 2002). In addition, the research itself could be impacted, since HCI design inconsistencies could introduce “contaminants” within the study designs (i.e., biasing one condition in favor of another). Hence, standards and productive constraints could be extremely useful for guiding the design decisions related to technological environments for CSCL research.

The adoption of principles and parameters that guide HCI design of CSCL tools can contribute significantly to make them more consistent, reducing friction with the user (students and teachers) and improving research control.

This research defines a framework for HCI design for the specific context of a pedagogical model called Knowledge Community and Inquiry (KCI), a CSCL model that guides the design of collective inquiry curriculum in which all students in the class (or across multiple classrooms) work together to advance their collective progress on a set of well defined learning goals. KCI designs include a range of specific activities, materials, tools and environments that support student and teacher interactions, including a “knowledge base” that is constructed through user contributions, and a wide range of inquiry tasks that make use of such knowledge as a resource (Slotta, 2013; Slotta, Tissenbaum, & Lui, 2013; Slotta & Najafi, 2012). A goal of this research is to provide a formal description - or “ontology” - of the kinds of elements and interactions entailed by a KCI design. While this ontology will not in itself be sufficient to ensure effective designs, it will offer an important step in that direction, supporting a higher level of abstraction than modeling languages, and allowing for a direct link between design components and user interface elements. The hope is that by applying this approach within the well defined context of KCI, the resulting ontology might be extended to other pedagogical approaches, supporting a broader class of technology environments for CSCL research.

The research focuses on a recent design-based research study of a KCI curriculum for elementary science called WallCology, in which students explore a set of digital ecosystems embedded within their classroom walls. The WallCology simulation provides an object of inquiry, and is part of a larger class of such interactions known as Embedded Phenomena (Moher, 2006). Students are engaged in the fiction that the entirety of each classroom wall is populated by "digital insects”, rendered as a rich simulation that is visible only through “wallscopes” --
computer displays affixed to the walls that appear to show an x-ray view into the wall’s interior. Students investigate the WallCology simulations, working collectively to understand the food webs within each wall, as well as how the species populations depend on temperature and habitat variables. The task is designed so that students build a collective knowledge base, making discrete observations of species, tallying relationships, and building hypotheses about habitat and climate dependencies. Taken together, their observations result in a community “knowledge base” which serves as both a product of and a resource for their inquiry. After coming to a collective understanding of the food webs and species sensitivities within each wall, the students work in small groups to solve a variety of rich ecological problems that are introduced into the ecosystems (i.e., invasive species, environmental warming, and habitat degradation). Student inquiry is scaffolded by a variety of technology and paper-based environments which help guide their progress. Curricular goals include the understanding of classification of species, populations, habitat preferences, food chains, predator-prey relationships, adaptation, and response to environmental change (López Silva, Gnoli, & Moher 2012).

One major technology environment employed within WallCology was called Common Knowledge (CK), which supported student observations, hypotheses, and reports on experiments. CK leverages an underlying technology framework called the Scalable Architecture for Interactive Learning (SAIL) which enables real-time updates amongst all peer devices. In other words, when a student using a tablet adds an observation, this appears immediately on all other student tablets, as well as on the teacher’s Smart board application. CK allows students to add their ideas and observations to a collective knowledge base, which then served as a resource in their subsequent inquiry (Fong, 2014).

This thesis begins with a literature review, emphasizing the theoretical perspectives of collective inquiry, including learning communities and knowledge building, as well as HCI design, and efforts to build specifications and standards for learning design. Next, I describe the method of this research, reviewing WallCology and the broader research program of an enactment of WallCology in Toronto, 2015 (Slotta, Quintana, Acosta & Moher, 2016; Slotta, Quintana & Moher, 2016) to identify the kinds of interaction that occur between students, teachers, and the digital learning environment during the collective inquiry. I describe my method of developing the ontology, and discuss possible limitations. In Chapter 4, I develop the the HCI ontology for WallCology, defining all elements and discussing the product. Finally, I extend and consolidate
that ontology by adding other types of interactions that could enrich future KCI model implementations, which informs my development of an HCI design framework. The goal for this framework is to support the wide range of possible interactions that occur within CSCL designs, and to guide the design of learning environments and technologies based on the SAIL architecture.
Chapter 2
Literature review

2.1 Inquiry-oriented learning

In 1910, Dewey recommended the inclusion of inquiry in science curriculum beginning in elementary school (Barrow, 2006). He later reinforced this idea with the principle that "education in order to accomplish its ends both for the individual learner and for society must be based upon experience - which is always the actual life-experience of some individual." (Dewey, 1938, p. 113) Starting from this powerful concept, Dewey emphasized the need for developing a philosophy of experience and proposed an inquiry model consisted of six steps: (1) sensing perplexing situations, (2) clarifying the problem, (3) formulating a tentative hypothesis, (4) testing the hypothesis, (5) revising rigorous tests, and (6) acting on the solution. Since then, other relevant research have explored learning approaches based on students' direct engagement in investigative tasks (Schwab, 1960; Bruner, 1961; Karplus and Thier, 1967; Papert, 1980). This has been particularly emphasized for science education, with methods that recreate in the classroom the process of scientific production in laboratories (Linn & Slotta, 2000; Linn et al., 2006).

The result of such research has favored the vision of students as individuals willing to engage in scientific practice and to build knowledge from it, and of instruction as the provision of the conditions and opportunities for such engagement (Linn, Songer, & Eylon, 1996). This understanding of learners and the instructional process has inspired a breadth of research and initiatives in the broad category of “inquiry” learning, with encouraging results. White and Frederiksen (1998), for example, have advanced the notion of the importance of incorporating metacognitive skills and knowledge as a component of inquiry-oriented curricula. According to them, metacognition on the inquiry process can be stimulated during the acquisition of subject matter knowledge through curricula designed to develop awareness of the inquiry cycle. To this end, they suggest a model in which:

[...] students pursue a sequence of research goals in which they first formulate a question and then generate a set of competing predictions and hypotheses related to that question. In order to determine which of their competing hypotheses is accurate, they then plan and
carry out experiments (using both computer models and real-world materials). Next, they analyze their data and summarize their findings in the form of scientific laws and models. Finally, they apply their laws and models to various situations. As they do this, they reflect on both the limitations of what they have learned (which suggests new questions) and on the deficiencies in the inquiry process itself (which suggests how it could be improved). Thus, after this reflective process, students are back at the beginning of the cycle with a new or refined question and a revised approach to inquiry. (White and Frederiksen, 1998, p. 4)

Linn and Songer (1993) also addressed learners' meta-awareness on the inquiry process. According to their research, after students engage in reflection on the nature of scientific investigation, they have changed their stance towards scientific knowledge, obtaining both a better understanding of the scientific principles that have been studied and a greater ability to apply them to everyday situations.

A wealth of research has investigated the role of computer-based learning environments for inquiry. In general, this work has found that, when adequately coordinated with other elements such as curriculum, pedagogy, assessment, teacher development and other aspects of the learning environment, technology can be a significant factor in creating environments more conducive to learning (Bransford, Brown, & Cocking, 1999; Greeno, Collins, & Resnick, 1996). The coordination of these elements is especially useful for the construction of an environment endowed with some fundamental characteristics for a greater efficiency of the learning process, such as active engagement, participation in groups, frequent interaction and feedback, and connections to real-world contexts. In this light, technology-enhanced inquiry-based learning could be seen as fostering the development of higher-order skills, such as critical thinking, analysis, and scientific inquiry (Roschelle et al., 2000). It has also been argued that technology-enhanced inquiry can promote higher levels of knowledge integration compared to more traditional approaches (Lee et al., 2010).
2.2 Collective Inquiry and Learning Communities

The learning community approach is based on the notion that learning is more efficient and effective when it is embedded in a rich social context (Bielaczyc & Collins, 1999). This grounds learners' identity as active builders of knowledge, with learning seen as a social and cultural enterprise. Hence, learners take responsibility for developing their own questions, discussing the ideas of others, and evaluating their progress and that of the community as a whole.

Two research projects in particular, serve to illustrate distinct approaches to the investigation of learning communities in classrooms: Fostering Communities of Learners (FCL -- Brown & Campione, 1994) and Knowledge Building (KB -- Scardamalia & Bereiter, 1989; 1991). Both projects started from the assumption that the 21st century education should shift the focus on individual progress to one on collective advancement. Thus, instead of focusing on strategies for individually getting each learner to draw more from their educational process, these approaches began to investigate how groups of learners could incorporate a collective epistemology and progress as a community. However, the two projects differ in their level of emphasis on learning goals, directed learning activities, and the primacy of ideas or student-directed inquiries.

In many learning community studies, students are engaged in activities that mirror those of scientific research communities, with learners acquiring agency to progress in their own inquiry, while mutually building on peer findings, and sharing data and information. In this approach, learners engage collectively in a curricular enterprise scaffolded by activities and practices that lead them toward well-defined learning goals (Slotta, Quintana & Moher, 2016). This is characteristic of both FCL and KB, although FCL tends to follow a more prescriptive formula for student activities, while KB emphasizes the advancement of ideas, and does not prescribe any particular set of activities. A third model for learning community, which also reflects the values of collective epistemology and knowledge construction is that of Knowledge Community and Inquiry (KCI). KCI is closer to FCL than KB, but does introduce an emphasis on collective knowledge construction, as well as a technology infrastructure for a community knowledge base that emerges as a resource for and a product of the inquiry on the targeted domain (Slotta, 2013; Slotta & Najafi, 2010; Slotta, Tissenbaum, & Lui, 2013). While it would be suitable to say that the products of FCL and KCI are “curricular” in nature, this terminology would not be a good fit
to KB, where the specific activities and products of the community are far less determined. These three models will be discussed in turn.

2.2.1 Fostering Communities of Learners

Fostering Communities of Learners (FCL) was grounded in Vygotsky's (1978) notion of learners as active constructors of knowledge (Brown & Campione, 1994). FCL establishes the classroom as a learning community, engaging students in carefully designed sequences and cycles of research-like activities designed to promote high levels of cognition and metacognition. The method is designed as a cycle of three components: research, sharing, and a consequential task. Each of these components has a set of activities designed to support the cycle. The initial stage of research is focused on activities that stimulate reading, writing, listening and viewing, such as research seminars, guided reading and writing, and peer- and cross-age teaching. Next, learners share what they have learned, through activities such as jigsaws and cross-talks. Finally, students must perform a consequential task where they must construct a representation of what they have learned, through exhibitions or other transparent and authentic assessments.

Unlike most of the other models analyzed in this thesis, FCL does not prescribe any specific technological support, relying on the physical environment of the classroom as a stage for interaction between educators, groups of learners and objects of study.

2.2.2 Knowledge Building

Knowledge Building (KB) strives to help learners develop a sense of collective cognitive responsibility (Scardamalia, 2002), establishing a culture of collaborative knowledge advancement in the classroom that prepares children as active participants in the knowledge society (Bereiter & Scardamalia, 2010). This includes transferring a large amount of freedom to the learners concerning their cognitive strategy, making them responsible for "knowing what needs to be known and for insuring that others know what needs to be known” (Scardamalia, 2002). Students must take collective responsibility for ensuring that the community achieves its goals of innovation and knowledge creation (which were actually defined by the community
itself). In this sense, KB understands learning as a byproduct of the collective process of innovation and production of new knowledge. According to Scardamalia and Bereiter (2006), this fundamental shift from seeing students as learners and inquirers to recognizing them as constituents of a knowledge building community involves the internalization of a series of premises:

- Knowledge advancement as a community rather than individual achievement;
- Knowledge advancement as idea improvement rather than as progress toward true or warranted belief;
- Knowledge of in contrast to knowledge about;
- Discourse as collaborative problem solving rather than as argumentation;
- Constructive use of authoritative information;
- Understanding as an emergent construct.

KB strongly relies on technological support to mediate interactions within the community and to structure the process of knowledge creation. In fact, the first mention of the term "knowledge building" (in the specific context of this pedagogical model) occurs in the early academic publications that described a technology known as Computer Supported Intentional Learning Environments (CSILE; see Scardamalia, 2004). With the emergence of the World Wide Web, CSILE gave way to the Knowledge Forum (KF) as an asynchronous discourse environment for collective knowledge creation and advancement -- a technology environment specifically tailored to KB support (Scardamalia, 2004). Students contribute to KF by adding ideas, theories, evidence, reference material, and questions through the creation of multimedia "notes", which other community members can read, link, build on and rise above. The note creation is scaffolded by technology features that guide the discourse, making it conducive to the culture of knowledge building in the community.

2.2.3 Knowledge Community and Inquiry

Knowledge Community and Inquiry (KCI) is a pedagogical model that supports the design of curricula in which learners work collectively in inquiry-oriented activities designed to drive their progress toward well-defined learning goals (Slotta, 2013; Slotta & Najafi, 2010). KCI curricular
units are co-designed by researchers and the teachers who will implement them, thus ensuring that curriculum expectations are met (Roschelle & Penuel, 2006), and typically extend over several weeks (Slotta & Najafi, 2010). KCI has been used to ground the design of a number of science units on different topics. In secondary schools, topics included human health (Peters & Slotta, 2007), global climate change (Najafi, Zhao, & Slotta, 2011), physics (Tissenbaum, Lui, & Slotta, 2012) and evolutionary biology (Lui & Slotta, 2012); and a unit on ecology was enacted in elementary schools (Cober, 2012). In addition, research for a KCI implementation in a literary studies secondary curriculum is currently in initial phase (Carvalho & Hall, 2016).

As in FCL and KB, KCI aims to promote a culture that leads to a collective epistemology and the production of knowledge by learners. The KCI approach seeks to do this by building a collective knowledge base, permanently accessible to learners, which serves both as a resource and as product of their inquiry process. The knowledge base and the inquiry activities that lead to its construction are carefully designed to guide students toward targeted learning goals. Teachers assume the role of expert collaborators, as well as the task of orchestrating the flow of activities, sometimes through scripted interactions with learners. To achieve these goals, the design of KCI curriculum is guided by four principles (Slotta, 2013):

1. Students work collectively as a knowledge community, creating a knowledge base that is indexed to a specific content domain.
2. The knowledge base is accessible for use as a resource as well as for editing and improvement by all members.
3. Collaborative Inquiry activities are designed to address the targeted domain learning goals, using the knowledge base as a primary resource and producing assessable outcomes.
4. The teacher’s role must be clearly specified within the inquiry script, in addition to a general orchestrational responsibility.

Again, technological supports play a central role in KCI curricula. In addition to helping teachers orchestrate the flow of activities, technology is a key resource for scaffolding of inquiry activities and the knowledge base. For that purpose, the first KCI enactments resorted to wikis, with predefined structures, to which learners contributed (Slotta & Najafi, 2012). To support the design and development of such technologies, Slotta and his colleagues developed the Scalable
Architecture for Interactive Learning (SAIL; see Slotta, Tissenbaum & Lui, 2013). SAIL is a technology architecture composed of data models and APIs loosely connected in a generic and extensible open source framework that grounds the development of learning environments that coordinate complex sequences of pedagogical activities, including student grouping, material delivery and task assignment (Slotta, 2013). Using SAIL, the KCI team is able to quickly develop a wide range of interactive materials, tools and environments. This thesis reports on the one such environment, used in the WallCology research, known as Common Knowledge (CK). It will develop an interaction ontology to describe CK, then extends this ontology to create a framework that could be applied to any SAIL environment.

2.3 Challenges of designing technology environments

2.3.1 HCI challenge: What forms of interaction do we need to support?

The first challenge we face in building an HCI design framework is to define what types of interactions it must support. The definition of such scope demands a review of the literature on interaction design for CSCL, more specifically for knowledge and inquiry communities, which is the focus of this research.

One important contribution to this end is the framework for analyzing argumentative knowledge construction, proposed by Weinberger and Fischer (2006). They start from a multidimensional view of the process of argumentative knowledge production, considering that the arguments learners construct when interacting with each other during a collective learning process have the dual function of "acquire knowledge about argumentation as well as knowledge of the content under consideration" (Andriessen, Baker, & Suthers, 2003). Based on this principle, they propose that the discourse produced during the process of collective knowledge construction must be analyzed and evaluated in its multiple dimensions: (1) the participation dimension, (2) the epistemic dimension, (3) the argument dimension, and (4) the dimension of social modes of co-construction (Weinberger and Fischer; 2006). In this way, if we consider the technological support as a platform for the construction of this collective discourse, and consequently the production of knowledge, we can adapt this framework for analysis of the outcome as a heuristic

for the design process that aims to support the achievement of such results. In other words, an optimal HCI design would be one able to provide solid support for all dimensions of speech, or at least for the dimensions that are particularly related to the goals of the learning experience it is intend to support.

To this end, the design of technological support should be concerned with facilitating the various tasks and activities characteristic of each dimension and meeting the diverse demands of each one. In the participatory dimension, it is important to stimulate the most homogeneous participation possible, eliminating possible blockages and increasing learners' awareness of their participation levels. In the epistemic dimension, it is necessary to support the construction of a problem space and a conceptual space, as well as the appropriate relations between them as well as with students’ prior knowledge, minimizing opportunities for non-epistemic activities and off-topic digression. In the argument dimension, the concern should be to facilitate interaction through arguments and counterarguments, and their integration and advancement, by stimulating grounded and qualified claims without blocking the space for non-argumentative discourse, such as questions and meta-statements. Finally, in the dimension of social modes of co-construction, the design should aim at negotiation support and collective organization to task execution and to promote the awareness of the collective process of knowledge production, evidencing to learners the importance of the contribution of others and the collaborative nature of the process (Weinberger and Fischer; 2006).

A model of collaborative knowledge-building proposed by Stahl (2000) also contributes to the identification of interactions that an HCI design framework for CSCL should be prepared to support. This model understands learning as a knowledge-building cycle, with both personal and social dimensions, that include a number of distinguishable phases (Stahl, 2000). Stahl represents this cycle in the following diagram:

From this model, it is once again possible to draw parallels between the activities and tasks characteristic of each of these phases with the objectives that the technological support design should seek to achieve. Thus, it would be necessary for the technology tool to allow interactions such as: addition of textual content, creation of representation of personal perspectives, comparison and relationship between statements and perspectives, asynchronous discussion, complex representation of notes, discussion and consolidation of conventions and definitions in the form of a glossary of group knowledge, negotiation, bibliographic discussion, and formalization and representation of collective knowledge (Stahl, 2000).
2.3.2 Design of Graphical User Interfaces (GUI)

2.3.2.1 Historic perspective

Graphical User Interfaces (GUI) are so ubiquitous that it's easy to forget that there was a time when we lacked them. In 1945, Vannevar Bush published his famous article "As We May Think", summoning scientists around the world to devote their efforts, when peace returned, to organizing the whirlwind of scientific information produced during the war. After that, almost four decades passed until typed commands ceased to be the predominant form of computer interaction (Figure 2).

The first significant advance for the development of graphical interfaces came from Ivan Sutherland in 1962, at the Massachusetts Institute of Technology (M.I.T.). Sutherland's PhD research originated the Sketchpad, a graphics system that used a light pen to manipulate objects on a display. At that time, even without the benefit of historical perspective, Sutherland accurately described the importance of this technological innovation:

Heretofore, most interaction between man and computers has been slowed down by the need to reduce all communication to written statements that can be typed; in the past, we have been writing letters to rather than conferring with our computers. For many types of communication, such as describing the shape of a mechanical part or the connections of an electrical circuit, typed statements can prove cumbersome. The Sketchpad system, by eliminating typed statements (except for legends) in favor of line drawings, opens up a new area of man-machine communication. (Sutherland, 1963, p. 17)

However, it would be the mouse, a device developed in 1963 by Douglas Engelbart at the Stanford Research Institute (SRI), which would become the most dominant tool for manipulating computer graphics, enabling the development of modern GUI (MacKenzie, 2012). The mouse, in its current form, was patented by Xerox in 1974 and popularized with the release of the Macintosh by Apple in 1984, which also had the first GUI to reach the mass market (Galitz, 2007).

2.3.2.2 Theories of interaction

The field of HCI design (and by extension, of GUI design) has become steadily more complex as new technologies have emerged, giving rise to new forms of interaction between humans and computers. The theoretical body on the field grows in the same proportion, as new researches are dedicated to understanding this phenomenon. Two theories have been especially influential in HCI: Distributed Cognition and Activity Theory (Rogers, 2012).

HCI designers have commonly used the distributed cognition approach to seek to identify possible consequences of transformations in the media in which information is represented, and thereby inform new designs and changes in existing designs (Rogers, 2012). This approach analyzes the cognitive phenomena from the identification of a cognitive system that is not
absolutely internal or external to the individual, but includes it alongside other individuals, artifacts, and internal and external representations of information. The interactions between people, artifacts and the environment are thus shaped by this cognitive system, not by specific components of it (Hutchins, 1995; Hutchins, Hollan, and Norman, 1986). Based on this concept, distributed cognition analysis can be applied to HCI design to examine how individuals collaborate to solve problems, how knowledge is accessed and shared, and what is the influence of verbal and nonverbal communication in the process (Rogers, 2012).

Activity Theory, on the other hand, seeks to inform the HCI field by studying the levels of an individual's consciousness when performing a particular activity, its objectives and motivations, and the mediating role of the artifacts (Bannon and Bødker, 1991; Nardi, 1996). The model identifies three levels of consciousness: "operations" are mechanical and routinized behaviors; "actions" are defined as an intermediate level characterized by conscious planning; and "activities" are behaviors with a higher level of awareness, reflection and attention. According to Bannon and Bødker (1991):

> These operations which allow us to build houses or do nursing without thinking consciously about each little step are often transformed actions, i.e. we conduct them consciously as actions in the beginning. Through learning we transform them into operations, but on encountering changed conditions, we may have to reflect on the consciously again, and thus make former operations once more into conscious actions. (p. 18)

Artifacts, both physical and abstract, have properties that can alter the level of consciousness of a human performing a task. Hence, GUI design can impact the cognitive process by manipulating the artifacts that mediate each interaction (Leontiev, 1981; Bannon and Bødker, 1991). For example, if an interface user who is performing repetitive operations receives a disruptive notification that demands action to be dismissed, they could move to a more conscious state, with consequences in their cognitive process.
2.3.3 Technology environments for collective inquiry and knowledge building

2.3.3.1 The Scalable Architecture for Interactive Learning (SAIL)

In the late 1990s, a multidisciplinary group at the University of California, Berkeley began a series of research on online environments for inquiry-oriented science learning (Slotta and Aleahmad, 2009). This research developed the Knowledge Integration Environment (KIE), a platform that aimed to scaffold students' work in collecting scientific evidence from the Web to support their inquiry on science curricula (Slotta and Linn, 2000). Later, this platform gave way to the Web-based Inquiry Science Environment (WISE, http://wise.berkeley.edu), a technology-enhanced learning environment that supports the development of a wide range of science inquiry projects. WISE allows teachers to create or customize learning materials to fit their curricula and learning goals and implement them to be delivered to students in the classroom (Slotta, 2004; Slotta and Linn, 2009). In 2003, the U.S. National Science Foundation funded the TELS center (Technology Enhanced Learning in Science) with the objective of researching computer-supported inquiry-oriented science learning. TELS intended to use the WISE environment to support models and content originally developed on other platforms (e.g., Pedagogica, Molecular Workbench and CC-Probe).

To enable such integration, a new version of WISE was developed, based on the Scalable Architecture for Interactive Learning (SAIL), an open source technology framework collaboratively designed and developed by a team of educational researchers, computer scientists, and technology developers from diverse universities (Slotta and Aleahmad, 2009). Beyond the immediate need of integrating WISE with the other technologies used by TELS, the initial version of SAIL aimed to be flexible enough to meet future designs and integrations. In the words of Slotta and Aleahmad (2009, p. 171) "SAIL hopes to provide a resource to an international community of designers and developers from diverse projects, leading to interoperability of technology tools, flexibility of interfaces, re-usability of content, and greater longevity and sustainability for our innovations.". Thus, in addition to scalability, the framework also sought to respond to the challenges of sustainability (learning materials should be future-proof), accessibility (the technology should be easy to use and install by researchers, content
developers, teachers and program specialists), and dynamic evolution (it should be able to incorporate new and more evolved technologies) (Slotta and Aleahmad, 2009).

To address those requirements, the system design comprised four separate layers of software, aiming at consistent reuse of the lower layers and easy alterations of the highest (Slotta and Aleahmad, 2009):

- The Architecture layer was the most basic, offering the basic set of rules for the construction of the other elements, and the "data model";
- The Framework is a set of software components that direct the Architecture to a more specific purpose. Among other functions, this layer is responsible for setting and managing the permissions of system users;
- An Environment is a system of interconnected components, developed on the framework, that manage the creation, storage and distribution of content among system users, assessment tools for teachers, and other similar functions;
- An Application is the top layer where the specific components for user interaction with the system are defined.

2.3.3.2 Knowledge Forum (KF)

A well-known and relevant example of technological environments for learning communities is the Knowledge Forum (KF; see Scardamalia, 2004; Scardamalia & Bereiter 2006). With the emergence of the World Wide Web, KF took the place of Computer Supported Intentional Learning Environments (CSILE; see Scardamalia, 2004) as software prescribed for the specific purpose of providing technological support to Knowledge Building (KB). KF aims to reinforce the principles of KB, with a technological instrumentation capable of inducing the community to consolidate and refine their ideas within a culture of collective innovation - ultimately seeking the discovery or production of new knowledge. Through KF, students contribute their ideas to a common knowledge base, which serves as a foundation for the reconciliation, distinction, synthesis and advancement of ideas within the community. This is done largely through textual notes, which can also include multimedia attachments, and are freely positioned (and repositioned) in a two-dimensional space called a "view". A KF community can include an undetermined number of views, thus allowing organization in sub-themes or sub-groups. The
note creation tool also reinforces and supports KB principles by offering a series of meta-discourse labels, or "scaffolds", that are intended to favor the construction of a discourse that is idea-centred and driven to innovation. Once published, notes become discourse units that provide connections for other members of the community to "build on" ideas already explored, or group a series of interconnected ideas to "rise above" them to a new level of discussion. KF also includes a robust set of analytic tools that provide to teachers, students, and researchers resources to evaluate various aspects of the community's knowledge production process and its outcomes.

Recent research by the Knowledge Building community has are explored ways to expand KF, increasing its capability of handling different types of digital content, to maximize opportunities for ideas and information produced in third-party tools to be freely used and fully harnessed in the knowledge building process. Such research also aims to make KF interoperable with other popular tools for creation and storage of digital content, using application program interfaces (APIs). The goal is to use such content not only as attachments to the natively created notes but as discourse objects per se (Carvalho, 2016).

2.3.3.3 Common Knowledge (CK)

Common Knowledge (CK) is a learning environment built on the SAIL architecture that has been adopted in several enactments of the KCI model. CK has been the subject of research since its initial development, which has informed the progress of the environment through several iterations (each tailored to the specific research needs for which it was being developed). In its first version, the environment contained a single application, a tool to support reflection and brainstorming used to complement to an inquiry activity about an embedded phenomenon on astronomy, known as HelioRoom. The application contained two interfaces, one "public" and one "private". The "private" interface was accessed through tablets by students working in pairs and scaffolded their hypothesis formulation on the phenomena they observed. The "public" interface was used in an interactive whiteboard, and supported a whole class brainstorming by allowing the teacher to open students' notes, color-code them and drag them around the screen to group them in themes (Fong, 2014).
In the following iterations, CK was enhanced with other applications which made it an environment capable of supporting a more comprehensive process of structured inquiry, scaffolding students' progression through several phases and activities, coordinating grouping, access (viewing and editing) permissions, and structuring the community knowledge base as a queryable, improvable resource. In the latest WallCology enactment, discussed below, CK provided support for a three-stage investigation that contained a variety of activities, some performed individually, others in small groups, or involving the whole class (Slotta, Quintana, Acosta, & Moher, 2016). The enactment of this curricular unit will be described in the next chapter, and the technological support provided by CK will be the basis for the ontology developed within chapter 4.

2.4 The need for design models and frameworks

Educational modeling languages (EML) are intended to support the standardization of learning design for the purposes of defining, designing, planning and discussing pedagogical scenarios, promoting and facilitating the exchange of learning units, or performing a unit on a platform or learning management system (LMS) (Dessus & Schneider, 2006). Rawlings, van Rosmalen, et al. define the concept of EML as a “semantic information model and binding, describing the content and process within a ‘unit of learning’ from a pedagogical perspective in order to support reuse and interoperability” (2002).

2.4.1 IMS-LD

IMS Learning Design (IMS-LD) is an EML that provides formal pedagogical standards to model technology-enhanced pedagogical implementations. IMS-LD adopts a theatre metaphor to describe a learning enactment, with the pedagogical scenario being referred to as a "play". The play is divided in "acts", within which "roles" such as learner, tutor, mentor perform a series of activities. According to Jeffery and Currier (2003), the model prescribes the description of learning objects and services (e.g. technological support) to each role. An act is concluded after all activities are completed, and it is followed by other acts until the completion of the play.
IMS-LD has an architecture in three levels (Jeffery and Currier, 2003):

- Level A is the core of the model, containing the method, play, act and role-parts elements in which people, activities and resources are coordinated.
- Level B describes internal (local) or external (global) properties that store information and conditions about a person, a role, or a learning design.
- Level C adds notification components that may be triggered automatically by events in the learning process, enabling richer opportunities for communication and automation of activities flow.

2.4.2 coUML

CoUML is an EML based on the Unified Modeling Language (UML), a modeling language used in software engineering, from which it lends formalisms and terminology. CoUML offers six models to describe learning activities (Derntl & Motschnig, 2007):

- A Course Activity Model (CAM) describes the activities that comprise a course, using an extension of UML activity diagrams.
- A Course Structure Model (CSM) describes designs with module dependencies that allow more complex designs.
- A Roles Model describes roles and their relations using UML case diagrams.
- A Goals Model formalizes learning goals their relationships using elements of UML class diagrams.
- A Documents Model describes the documents used and its relations to roles.
- A Course Package Model (CPM) adds a high-level description of the course.

2.4.3 LMS interoperability architectures

Another approach to standardization of learning environments that must be mentioned is that of software interoperability architectures, such as SCORM (Sharable Content Object Reference Model; see Bohl et al., 2002), MERLOT Web Services (Dietze et al., 2013), and GLUE!-PS (Group Learning Unified Environment - Pedagogical Scripting; see Prieto et al., 2011). These
technologies are not intended to support learning design itself, but they provide application program interfaces (API) or technical standards to integrate online learning contents with learning management systems (LMS), such as Moodle, which usually have their own interfaces. Thus, the adoption of this type of solution can indirectly impact HCI design decisions.
Chapter 3
Method

This chapter begins by reviewing the major research program in which this research was situated, the specific materials and activity design, as well as the technology environments that were designed. It then reviews the method used in this research to develop an ontology of HCI, and discusses its limitations.

3.1 Embedded Phenomena for Inquiry Communities (EPIC)

WallCology, the research described in this thesis, is part of a broader set of research known as Embedded Phenomena for Inquiry Communities (EPIC; see Moher & Slotta, 2012), developed in collaboration between researchers at the University of Toronto and the University of Illinois at Chicago (UIC). EPIC synergizes research on Embedded Phenomena (EP; see Moher 2006) and Knowledge Community and Inquiry (KCI; see Slotta, 2013), two pedagogical models that are complementary in an effort to implement the collective inquiry approach for elementary science curricula.

EP grounds the development of digital simulations that are embedded in the classroom environment, through computer displays, ambient sound systems, or other technology attached to the furniture, floor, or walls (Moher, 2006). EP simulations are usually kept running for several weeks, even when they are not being observed by students, aiming to reinforce the concept that, in nature, "things happen when they happen," without considering the schedules of scientists. This way, students may arrive in class by morning and discover that the EP they are investigating has undergone a drastic change (e.g., an invasive species has altered the ecosystem's balance). This provides students with an object of inquiry which is immersive and complex enough to foster the development of a collective epistemology for inquiry-based learning. KCI model, in turn, offers pedagogical support for the exploration of the phenomenon, providing a scaffolding framework that leads to collective inquiry toward curriculum learning goals (Slotta, 2013).
3.1.1 The EPIC Co-design Team

The co-design team that worked on the WallCology enactment held in Toronto, 2015, was distributed to two groups, being one based at the University of Illinois at Chicago (UIC) and the other at the University of Toronto. The American team included a lead researcher, a domain content expert, two graduate students, and two technologists who were responsible for the development of the embedded phenomena, the simulated ecosystems that would be the object of inquiry. The Canadian team was composed of a lead researcher, four graduate students, a technologist, and the two teachers of the classes where the curricular unit would be implemented, in the Dr. Eric Jackman Institute for Child Study, an elementary school in Toronto. This team was responsible for scaffolding the inquiry process according to the school's curricular expectations, designing and developing the technological support, and supporting the enactment. Two of the graduate students who participated in the team had relevant experience as interaction designers and contributed to this aspect of the project.

3.1.2 WallCology

The research reported in this thesis took place in Grade 5/6 classrooms of each of the co-designers teachers (n=24; n=23), at the Dr. Eric Jackman Institute of Child Study, a laboratory school in Toronto. The enactment started on October 8th, 2015, and spanned through twenty classes, ending on December 14th, 2015. The WallCology Embedded Phenomena (WallCology EP) was kept embedded in the classrooms for nine weeks, during which students investigated it using Common Knowledge (CK), a learning environment developed to support collective inquiry. In the final four classes, students engaged in discussions about connections between what they had learned and actual ecological problems, as well as in a videoconference session with the ecologist who contributed domain content expertise to the development of WallCology EP.

In both classes, WallCology EP was supported by four computer monitors affixed to each of the classroom walls. These monitors, called wallscopes, displayed simulations of ecosystems with different fictional species of insects and vegetation (Figure 3).
Students were engaged in responding to the fictional narrative that the wallscopes revealed a real x-ray vision of what was actually taking place inside the walls. The distribution of wallscopes at different points in the classroom justified the occurrence of different ecosystems. For example, some wallscopes revealed the existence of cold water pipes, others of hot water pipes, or a larger area of bricks. Consequently, some ecosystems were predominantly formed by species that preferred a warmer environment, others by species that preferred lower temperatures, etc. The wallscopes displayed the internal temperature of the ecosystem, allowing students to identify the correlations between species and temperature in the course of their investigations. In total, there were eleven different species, each ecosystem containing four or five of them, distributed according to their adaptability to the characteristics of each habitat (Table 1). No information on the species was previously given to students, but they could be directly observable (e.g.: food web interactions) or inferred (e.g.: temperature preferences). However, the complexity of the information set was high enough to make it impossible for a single student to understand the
integrality of the phenomenon, which provoked the need for cooperation and collaboration. Thus, students were divided into four groups, with each group specializing in an ecosystem, and developing stewardship for it.

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Table 1. WallCology species, their attributes and food-web relations.

A key conceptual feature of WallCology EP are the "perturbations" that occur in ecosystems after a certain time. After four weeks of inquiry, when students were already familiar to the species and their ecosystems, they found significant changes in the simulations upon arrival in class. Each ecosystem had been affected by a different type of perturbation, resembling real ecological problems, producing different consequences: (1) pipe collapse, resembling habitat degradation; (2) invasive species (resource); (3) invasive species (predator); (4) temperature increasing. WallCology EP is grounded on an underlying biological model, co-designed with an expert biologist, that drives the simulations based on the interrelationships of a complex
biological system of predators, preys, environmental conditions, and other factors. Thus, the environmental perturbations led to extinctions or to significant decreases in populations of species not adapted to the new conditions, or to uncontrolled population increase of other species that, for example, had their predators' populations reduced.

At this point, students were given the opportunity to interfere with their ecosystems, with the aim of responding to the perturbation. However, just as in the case of environmental scientists dealing with real ecosystems, it was not possible for students to manipulate abiotic characteristics, such as increasing or reducing environmental temperature, or artificially rebuilding degraded parts of the habitat. On the other hand, students were able to manipulate biotic variables, such as reducing or increasing the population of existing species, or introducing new species. Nevertheless, the underlying biological model continued to operate, sometimes making unviable the changes made by students (e.g.: students introduced a predator in order to reverse the uncontrolled growth of other species, but the new species was unfit to the habitat temperature and was eventually extinct).

These characteristics and interrelations have formed a sufficiently complex object of inquiry to derive a wide range of investigative activities. Students identified the species, observed their behavior and preferences, classified them according to their characteristics, understood the food webs of each ecosystem, and made predictions and assessments of the consequences of changes in ecosystems. Moreover, the distribution of species by the different ecosystems and the complexity of their interrelations demanded the collaboration between groups for the complete understanding of the phenomenon. For example, in ecosystem 1, species A was at the top of the food chain and predated species B, but in ecosystem 2, species C (non-existent in ecosystem 1) predated species A. Thus, only the collaboration between these two groups would make it possible to fully understand the position of species A in the food chain.

### 3.1.3 WallCology Technology Environment

These inquiry activities and the collaboration between groups were mediated and supported by a learning environment known as Common Knowledge (CK). CK was accessed individually by each student through iPads or laptop computers. In addition, it had components that were
accessed on a SmartBoard positioned at the front of the room, allowing the simultaneous engagement of all students in some activities. The knowledge community interactions through CK will be described and discussed in the next chapter.

One other important technology environment that played a role in student and teacher interactions within the WallCology KCI unit is known as Nutella, which is the delivery platform for embedded phenomena. Nutella was adapted in this study with specific features for the curriculum, including sliding panels that displayed environmental variables (temperature, habitat coverage). An integrated graphing tool was also developed, allowing students to select which species they want to graph, then generating comparison graphs, that served as evidence in support of student reasoning. Nutella also provided logical controls for the ecosystem disruption (the temperature begins to increase, or certain kinds of habitat begin to disappear, or certain invasive species grow more prominent). It also included controls for students to respond to those perturbations, by adding new species, or reducing existing ones (i.e., through trapping).

While CK served as the platform for building community knowledge, creating hypotheses and experiments, and reporting evidence about the outcomes of those experiments, Nutella served as the platform for running the simulations, generating the population graph data, and interacting with the simulations directly. These two environments were loosely coupled, meaning that they never read or wrote any information to the same knowledge base. Although students could generate photos from Nutella and save those to the CK knowledge base.

3.2 Co-design

Co-design has been recognized as an efficient method for developing educational innovations suitable for implementation in real classroom environments (Roschelle, Penuel, & Shechtman, 2006). This approach engages in the design and planning of learning activities the various stakeholders involved in the process, such as teachers, researchers, learning designers, and technology specialists. Thus, it is intended that the proposed innovation can be appropriately tailored to the educational environment in which it will be implemented and investigated. In a co-designed project, all members of a team, usually multidisciplinary, are symmetrically involved in the discussion about the intended innovation. Consequently, the diverse and
complementary perspectives contribute to the wealth of knowledge and expertise, leading to more advanced ideas and solutions, while the possible constraints and difficulties of each aspect of the project are considered and the various objectives are aligned. When learning activities or environments are co-designed, the involvement of teachers favors the achievement of their pedagogical and curricular objectives, consequently increasing the chances that the innovation will be satisfactorily implemented in their classrooms (Roschelle, Penuel, & Shechtman, 2006). In parallel, the participation of researchers tends to contribute to broaden and deepen the understanding of the phenomenon to be investigated and to insert the design in a context of scientific production in which it can be useful to advance other research.

Considering the importance of technology support for both the EP and KCI models, the co-design teams of EPIC projects typically include interaction designers and technology specialists, in addition to teachers and researchers (Acosta, 2013, Cober, 2012; Fong, 2014). The participation of these specialists aims to ensure that the technological component of these projects incorporates the best practices of interaction design and that they are implemented through the most effective technical resources. Also, this team configuration enables agile development of custom designed technologies to meet the pedagogical objectives of the project, minimizing the need to resort to ready-made solutions, possibly less adequate, due to lack of capacity to develop proprietary solutions.

3.3 Developing an ontology

This thesis adopts the definition of "ontology" offered by Gruber (1993, p. 199): "A body of formally represented knowledge is based on a conceptualization: the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them". The use of ontologies as a method of knowledge representation intends to capture static domain knowledge in a generic way and offer a conceptual standardization upon understanding of that domain, which may be reused and shared across applications and groups (Chandrasekaran, Josephson, & Benjamins, 1999). Thus, an ontology of human-computer interactions aims to produce a body of conceptual representations of human and technological instances that interact within a technologically mediated system, including the interactions themselves and the interfaces that support them. In the specific context of HCI design for SAIL-
based learning environments, the ultimate objective is for this body of conceptual conventions to assist in assessing the adequacy of GUI design to pedagogical objectives and to inform the development of future implementations, composing a conceptual framework for HCI Design that also includes design principles and implementation guidelines.

In order to develop an ontology of the HCI for WallCology, this research started from the definition of the conceptual classes that compose the system, moved to the identification of the relations between them and, finally, developed an exhaustive inventory of the ontological instances and their classification. To this end, I analyzed the complete set of graphical interfaces designed for the CK environment used in WallCology to verify the interaction modalities they mediated, the lesson plans co-designed with teachers to identify human components, pedagogical objectives and intended interactions, and the knowledge base produced by the community during the enactment.

3.4 Limitations of this Approach

A possible conceptual limitation of this approach lies in the fact that some definitions of "ontology" require the formalization of "axioms", that is, general rules about relations between classes and instances. Although it is possible to infer axioms from the conceptual representation produced by this research, they were not formalized, since this would extrapolate the previously described objectives. Nevertheless, this research could face terminological objections from those who defend more restrictive definitions of ontology.

Furthermore, by focusing specifically on HCI, the results of this research fail to analyze interactions not mediated by technological support (e.g., verbal communication between teachers and students, or the use of paper-based artifacts, which occurred often during extemporaneous interactions). Thus, the research does not contribute to the judgment about the adequacy of resorting to technological mediation to a given interaction. Rather, this research is restricted to identifying all forms of interactions that were mediated during Wallcology (Ch. 4) and that potentially could be technologically mediated within the scope of the KCI model (ch. 5), and to providing guidelines for designing such interactions in the form of graphical user interfaces.
Chapter 4
WallCology 2015 HCI Design

4.1. Overview

This chapter will focus on the interaction design of Common Knowledge (CK), a learning environment that was developed in close conjunction with the design of KCI research units, including Wallcology, providing a technology support. As discussed above, the goal is to develop an ontology of Human Computer Interactions (HCI) that occurred during the enactment, including examples of how they were supported by the CK design. This discussion will not address other types of interactions that occurred during the curricular unit that have not been mediated by technological support. After identifying the ontological classes and instances of the HCI design of WallCology, their adherence to the learning design of the unit will be discussed. The following chapter will start from this discussion to extend this ontology and take it as the basis for a HCI design framework that supports the development of future SAIL-based learning environments.

4.2. HCI Ontology

This ontology covers all components of HCI for collective inquiry in WallCology, from human agents (students and teachers) to the devices, interfaces and functions of CK learning environment. It does not include the technological support for the WallCology Embedded Phenomena (WallCology EP) that was investigated by students. In this enactment, four screens of approximately 21 inches were affixed to the walls of the classrooms, each displaying a different simulated ecosystem. Such screens will not be considered in this ontology, nor the simulated ecosystems will be considered as being part of the Graphical Interface class, since they fulfill the function of inquiry object, not of inquiry support tool. In other words, the function of these screens and the software they display is not to provide technological support to facilitate and conduct the inquiry process, but to present the problem that would be the object of collective inquiry.
4.2.1 Classes

This HCI ontology for WallCology has its instances distributed into four classes: 1) Entity; 2) Device; 3) Graphical Interface; and 4) Interaction. Next, I will describe the basic characteristics of each of these classes.

4.2.1.1 Entity

Entities are the different types of actors in the system: Students, Groups, Teachers, and the Knowledge Base. The entities fulfill different roles, which will be described later, and interact through the graphical interfaces supported by the different devices.

4.2.1.2 Device

Devices are the hardware component of technology support. The definition of the type of device for each function or stage of a learning design has a direct impact on the scripting of activities and the design of graphical interfaces. For example, the use of mobile devices may be critical to allow the free movement of learners through the environment, but their smaller screen size may cause limitations to GUI design. The enactment of WallCology in Toronto, 2015, used two types of devices: Handheld Devices and Large Screens.

4.2.1.3 Graphical Interface

Graphical Interfaces are the software component of the technological support. Graphical Interfaces should be designed to facilitate the various types of entity interactions, considering the limitations of each type of device and exploiting its resources to the maximum, to support the scaffolding of the inquiry process towards the learning goals. This enactment of WallCology relied on three different graphical interfaces: an Individual Learner Interface, a Group Interface and a Knowledge Base Representation.
4.2.1.4 Interaction

Each action or task that the entities must perform through technology support are classified as an Interaction. Thus, interactions are the different functions that the system must support. When organized and sequenced in different ways, a small repertoire of interactions can give rise to a virtually unlimited number of activities and inquiry dynamics. In this enactment of WallCology, the system supported nine different types of interactions.

4.2.2 Instances

4.2.2.1 Knowledge Base

Class: Entity

As previously mentioned, the first two principles of the KCI model are: "1) Students work collectively as a knowledge community, creating a knowledge base that is indexed to a specific content domain"; and "2) The knowledge base is accessible for use as a resource as well as for editing and improvement by all members" (Slotta, 2013). These principles underline the central role that the construction of a collaborative knowledge base has in the pedagogy proposed by this approach. Here, Knowledge Base is the instance of HCI design that corresponds to this pedagogical component of the KCI model and, consequently, of WallCology. Such central role in the pedagogical model confers to this instance some characteristics quite different from the other instances of the entity class. The most obvious of these differences is that the Knowledge Base is the only entity that does not correspond to a human agent, or group of humans, but to a computational component. In this way, this instance does not interact intelligently with others; however, it should still be considered an entity, as it responds to the interactions of other entities, and affects their actions. In WallCology, as in other implementations of the KCI model, the Knowledge Base was pre-modeled in the system, that is to say, the enactment did not start with a completely empty and unstructured base, but with predefined categories and structures to accommodate the information that would later be added by learners. This pre-modeling of information structures fulfills the fundamental pedagogical role of scaffolding the inquiry process, directing the interactions of the other entities towards the learning goals.
4.2.2.2 Teachers

Class: Entity

In WallCology, despite having a crucial role in co-designing the enactment and orchestrating the activities, teachers had very few opportunities for interaction through technological support. Teachers did not use handheld devices, so they could not directly contribute to the Knowledge Base, a task that was restricted to students. Also, teachers did not have their own graphical interfaces, with functions and permissions specially designed for them, such as communication with students or access to learning analytics. There was also no technological support for the orchestration, which was all done orally, through verbal commands to students. The only exception was a simple command in the Group Interface designed to support brainstorming, which paused the session, allowing teachers to easily get the attention of the whole class. This Group Interface, designed for brainstorming sessions, was the only point of interaction of teachers with the system, and will be described later.

4.2.2.3 Students

Class: Entity

Students are the main actors of the system. In WallCology, virtually all interactions mediated by technological support were performed by them, sometimes individually and sometimes in groups, that will be considered as a separate entity. Students accessed an Individual Learner Interface through iPads (or sometimes laptops) that allowed them to contribute to or consult the Knowledge Base.

4.2.2.4 Groups

Class: Entity

In WallCology, students were divided into four groups, each linked to one of the simulated ecosystems, in the expectation that the groups would develop a sense of stewardship over their ecosystems and concentrate their efforts on finding ways to "fix them" when environmental
problems were introduced. Thus, on several occasions, WallCology scripting treated groups of students as a cohesive unit of action. At such times, it was expected that the members of a group, after negotiating, would reach a consensus and act in a unified form, therefore, as an autonomous entity.

4.2.2.5 Large Displays

Class: Device

WallCology design included a SmartBoard at the front of the classroom. This interactive display supported the Group Interface designed for the brainstorming sessions, and a Knowledge Base Representation designed to serve as visual support for the periodic reports that the student groups made about their inquiries and discoveries for teachers and other groups.

4.2.2.6 Handheld Devices

Class: Device

IPads were the primary device for accessing the system. Each student received an iPad and used it to support all their interactions. Occasionally, some students opted for laptops, but the interface on both devices was the same. Often, students used the device's camera to produce visual evidence, photographing or filming their ecosystems for images that supported their assertions and hypotheses.

4.2.2.7 Individual Learner Interface

Class: Graphical Interface

An Individual Learner Interface was designed exclusively for WallCology, and developed over the SAIL framework. This interface was accessed through handheld devices, and it scaffolded the inquiry by offering students only the resources needed for each step of the process. Students used the Individual Learner Interface to individually add information to the Knowledge Base,
and to access, relate, and classify information added by themselves and other students, or generated automatically by the system.

4.2.2.8 Group Interface

Class: *Graphical Interface*

Brainstorming sessions involving the whole class were supported by a Group Interface displayed on the SmartBoard on the front of the classroom (Figure 4). This interface collected the contributions that students wrote in their Individual Learner Interfaces and displayed them as draggable cards. The teacher was able to expand these cards to discuss the content of contributions with the whole class. Dragging the cards, the teacher could group them in the corners of the screen, thus facilitating the discussion and negotiation to categorize the information produced by the students. This interface also contained the only tool designed to provide technological support for the orchestration of the learning experience, a button that allowed the teacher to remotely pause all Individual Learner Interfaces in order to get the attention of all students.

Figure 4. Group Interface.
4.2.2.9 Knowledge Base Representation

Class: Graphical Interface

An automatically generated Knowledge Base Representation was designed to provide visual support to periodic reports that student groups made on the status of their inquiry to share with others the knowledge they produced. This interface automatically collected the group's experience plans, their predictions of the outcome and their report of the actual outcome and displayed this information in the SmartBoard (Figure 5). Thus, the groups could demonstrate to the rest of the class the actions they intended to perform, explain their goals and describe what they learned after the experiment.

![Mission happy home](image)

Figure 5. Knowledge Base Representation.
4.2.2.10 Including and excluding learners in groups

Class: *Interaction*

After the students' first exposure to the four simulated ecosystems, when they had the opportunity to walk freely around the room and observe each of the four screens on the wall, the students were distributed into four groups, one for each ecosystem. Naturally, even this quick contact was enough so that some students developed preferences for a particular ecosystem that interested them the most. The technological support provided a tool that allowed the teacher to easily distribute students into groups, according to their preferences, or any other criteria. The solution consisted of pictures of the four ecosystems, to facilitate their recognition, and a list of the names of the students (Figure 6). When the teacher clicked on a student name and then on an ecosystem picture, the student was added to that group. In case of mistake or need to change, the teacher could click on that name again so that it returned to the list and could be moved to a different group.

![WallCology](image)

Figure 6. Including and excluding learners in groups.
4.2.2.11 Adding information to the knowledge base

Class: *Interaction*

Adding information to the knowledge base was the most fundamental interaction in the system. On multiple occasions, students were asked to contribute data, information, evidence, theories, ideas, questions, or previsions. The basic design solution for this type of interaction was composed of text fields, usually with a button to attach multimedia content (Figure 7). That way, students could photograph or record video or audio with their iPads and attach that material to their contributions.

![Figure 7. Adding information to the knowledge base.](image)

4.2.2.12 Categorizing information

Class: *Interaction*

Students were also asked to categorize the information they added to the knowledge base. To facilitate this type of interaction through the Individual Learner Interface, it was designed a bar (Figure 7) that students could use to indicate which ecosystem and species were related to the
information they were adding, and what was the category of that information's content (species, relationships, habitats, populations, real-world connections, or big ideas). The Group Interface also supported the act of categorizing information. In it, teachers found as "Add Theme" button that allowed them to add labels to areas of the screen (Figure 8). Teachers then could drag the students' contributions and place them around the labels, visually grouping similar ideas.

Figure 8. "Add Theme" button allowed to visually group ideas.

4.2.2.13 Filtering information

Class: Interaction

The metadata provided by students when categorizing their contributions was used to allow filtering of information during subsequent queries to the knowledge base. For consistency, the command bar for filtering was identical to that of categorizing (Figure 9). When students selected an ecosystem, type of information, and/or species they wanted to consult, the contributions that met those criteria were listed.
4.2.2.14 Editing information

Class: *Interaction*

Students could edit their own contributions, and only their own contributions, after adding them to the database. A dashed line served as a visual aid to facilitate the identification of the student's own contributions among the others (Figure 10). When a student opened one of their own contributions, the content was displayed in text fields and could be edited and resubmitted (Figure 11).
Figure 10. Dashed lines identify contributions from a student.

Figure 11. Editing information.
4.2.2.15 Accessing information provided by other students

Class: Interaction

In the case of contributions made by the other students, they were displayed with a similar design, but that sought to make evident that they were not editable (Figure 12).

Figure 12. Accessing information provided by other students.

4.2.2.16 Accessing information automatically provided or organized by the system

Class: Interaction

In addition to information added by the students themselves, they also had access to some information automatically provided by the system: population graphs of each species (Figure 13). Students could define a timeframe and choose the species whose population evolution they wanted to compare. Often, students would make screenshots of the screen of their iPads displaying population charts to use as evidence to support their hypotheses and findings.
4.2.2.17 Relating information

Class: *Interaction*

Students were required to relate information about species, in order to understand the food chain of their ecosystems. To support this task it was designed an interface component that allowed students to select two species whose energy transfer relationship they had identified, and to justify such claim (Figure 14).
4.2.2.18 Controlling activity flow (pausing and resuming activities)

Class: *Interaction*

In WallCology, orchestration was basically done orally by teachers. The only aid from the technology support was a "Pause" button on the brainstorming Group Interface that paused the session on the students' handheld devices, allowing the teacher to get the attention of the whole class (Figure 15).
4.3 Discussion

From the standpoint of software development and programming, the CK environment developed for this WallCology enactment comprised two applications: a mobile application for students to use through handheld devices, and another to support brainstorming sessions in SmartBoard. From the perspective of GUI design, these applications correspond to the ontological instances of the Graphical Interface class. The Individual Learner Interface and the Knowledge Base Representation were part of the mobile application, while the Group Interface corresponded to the application for brainstorming. It should be noted that the Knowledge Base Representation, although it was programmed as part of the mobile application, was used in the SmartBoard, what was done through its execution on a laptop computer connected to the SmartBoard.

Among other components, the software development environment included Bootstrap, a HTML, CSS, and JS framework for developing applications with responsive web design, meaning that such applications automatically adjust to different screen dimensions and formats. Thus, the GUI design was strongly influenced by pre-existing designs of interaction elements provided by the
Bootstrap framework. Bootstrap framework allows the installation of "themes" that work as "skins", replacing colors, typographic fonts, styles and other visual features of design elements. Since the two applications were developed separately, they used distinct themes with no visual consistency.

Despite the visual inconsistency between the two applications, the Bootstrap framework allowed rapid and agile software development, including some last-minute fixes and adjustments. This facilitated and accelerated the development of an environment that provided technological support for most interactions required by the learning design of WallCology. Some functions, however, were necessary during the enactment, but they were not supported by any of the graphical interfaces, and therefore they were executed directly by programmers in the database, or verbally by the teacher. Such interactions will form part of the extended ontology presented in the next chapter as the basis for the design framework that this thesis offers for the next SAIL iterations. Are they:

- Creating representation of personal identity (social profile);
- Defining and informing learning goals;
- Modeling the knowledge base (predefining hierarchies, relationships, and categories of information that will be added by learners and groups);
- Creating tasks;
- Sequencing tasks and activities;
- Creating groups;
- Setting access permissions;
- Deleting information.
Chapter 5
HCI Design Framework for SAIL

5.1 Overview

This chapter builds on the discussions in the previous chapters, mainly from the HCI analysis of the recent WallCology enactment, to offer an HCI Design Framework for SAIL. The goal is to fill the gaps related to guidance and support for interaction design for computer-supported inquiry-oriented learning, more specifically in the context of KCI model. To this end, this design framework is intended to be generic and flexible enough to support a broad variety of learning designs, in order to meet a wide range of pedagogical objectives.

This design framework comprises a series of conceptual design principles, guidelines for implementing a visual language for interface design, and an ontology of human-computer interactions that could emerge in a KCI enactment, with examples of GUI design solutions to support them.

5.2 Design Principles

This design framework underlines the special importance of three principles for the development of collective inquiry learning environments that offer optimum support to the KCI pedagogical model: (1) Interfaces should seek consistency to reduce friction with learners and increase the stability of the research environment; (2) Interface affordances and constraints should be conducive to the learning goals; and (3) Attractive interfaces are more efficient.

5.2.1 Interfaces should seek consistency to reduce friction with learners and increase the stability of the research environment

Consistency is an attribute widely recognized as desirable for interface design (Satzinger & Olfman, 1998; Sein et al., 1999; Mendel & Pak, 2009). Usually, consistency is related to a reduction of the cognitive load, which makes it especially important in designing learning environments (Galitz, 2007). Research have demonstrated that users complete tasks in less time
(Koyani et al., 2004) and with fewer errors (Ozok and Salvendy, 2004) when there is consistency in the visual and linguistic aspects of a web site. According to Galitz, consistency "establishes expectations, permits a person to employ conceptual learning and transfer training, and enables the user to easily anticipate the location of screen elements of interest" (2007).

In the specific case of SAIL-based learning environments, it must be considered that they fulfill the dual function of environment for learning and research. This may recommend a further increase in the importance of the attribute of consistency, since environments with consistent interaction design ideally could reduce the variables that can impact the research result.

5.2.2 Interface affordances and constraints should be conducive to the learning goals

The KCI method has as a principle that the inquiry activities are "designed to address the targeted domain learning goals" (Slotta, 2013). Conducting the community toward the body of knowledge that it is intended to acquire is done through the scaffolding of inquiry activities. Affordances and, on the other hand, constraints must be carefully planned in the interfaces that compose the learning environment, in order to contribute to this scaffolding. The ecological psychology approach, advanced by Gibson, is among the cognitive theories more relevant to the HCI field (Rogers, 2012). Gibson refers to affordances as the whole set of "action possibilities" latent in an environment (1977, 1979). Such latency depend on the ability of individuals to perform the action, but are independent of the ability of these individuals to perceive the possibility of action. In this way, the learning environment interface impacts on the scaffolding of the evolution of the inquiry process not only through the opportunities of action it offers, but also through its capacity to make learners perceive these opportunities for action. Thus, the careful design of the affordances and constraints of the interface is crucial to ensure that learners will be able to identify and take actions that drive the inquiry toward the learning goals.
### 5.2.3 Attractive interfaces are more efficient

Ortoni, Norman, and Revelle offer a psychological model that considers emotion processing as being result of three different levels of brain mechanism: reflective, behavioral, and visceral (2005). According to this model:

The visceral level is fast: it makes rapid judgments of what is good or bad, safe or dangerous, and sends appropriate signals to the muscles (the motor system) and alerts the rest of the brain. This is the start of affective processing. These are biologically determined and can be inhibited or enhanced through control signals from above. The behavioral level is the site of most human behavior. Its actions can be enhanced or inhibited by the reflective layer and, in turn, it can enhance or inhibit the visceral layer. The highest layer is that of reflective thought. Note that it does not have direct access either to sensory input or to the control of behavior. Instead it watches over, reflects upon, and tries to bias the behavioral level (Norman, 2002).

The process of perception traverses these levels in both directions simultaneously, so it has both a cognitive component (assigning of meaning) and an affective component (assigning of value) that influence each other through the release of neurotransmitters (Ortoni, Norman, and Revelle, 2005). Thus, according the research, "Positive affect arouses curiosity, engages creativity, and makes the brain into an effective learning organism" (Norman, 2002).

The aesthetic excellence must be recognized as an objective of the design of interfaces for learning environments that shall not be undervalued. Such excellence can be achieved by adopting a visual language that provides adequate support for design decisions that add aesthetic value to the final result, such as grid, typography, iconography, and color scheme.

### 5.3 Front-end design: Material Design

The adoption of a conceptual and technological support to the GUI design level can contribute to the outcomes to be harmonious with the proposed principles for HCI design of SAIL learning environments, as well as streamline the software programming and development stage. Material Design is a visual language proposed by Google that intends to function as an underlying visual
system for designing interfaces that are highly consistent across platforms and devices and that 
synthesize classic principles of design best practices. According to Jitkoff, Material Design was 
developed "as a metaphor to rationalize design and implementation, establishing a shared 
language to help teams unite style, branding, interaction, and motion under a cohesive set of 
principles" (2016). The name refers to the initial effort of the project to endow the digital support 
with physical, or "material", characteristics. Humans are accustomed to interacting with the most 
diverse materials, and unconsciously develop expectations about their physical properties. For 
example, if one uses a pencil to apply pressure to paper or wood, these materials will react 
differently, but both in predictable ways. Digital media, especially touchscreen devices, are 
capable of subverting this expectation. Material Design starts from the conception of a "virtual 
material" called Smart Paper, which blends the physical properties of paper with the unique 
features of digital media. The concept then proposes that digital designers should consider this 
conceptual Smart Paper as their raw "material" and abdicate of the ability to subvert their 
standardized properties, in order to develop interactions more consistent with users' unconscious 
expectations (Cousins, 2015).

Building on this basic concept, Google's team of designers has developed a fairly complete set of 
guidelines, tools, and features that facilitate and enhance GUI design (http://material.io). In 
addition, the community that gathers around the initiative have also contributed with a growing 
number of interesting resources such as themes or component libraries for various technologies 
such as Bootstrap (the front-end framework used in the latest implementations of SAIL; 
http://fezvrasta.github.io/bootstrap-material-design), React (http://getessence.io), AngularJS 
(http://material.angularjs.org), and CSS (http://materializecss.com). Therefore, the adoption of 
Material Design as a GUI design framework is modular and easily compatible with the 
technologies prescribed by SAIL for software development and programming. Thus, due to the 
harmony with the design principles proposed here, and to the variety and solidity of the resources 
and supports, the examples offered in the extended ontology that will be described next adopt 
Material Design as a visual language.
5.4 HCI ontology

This section extends the HCI ontology of the last enactment of WallCology, described in the previous chapter. It will be added of the functions that were needed in that enactment, but were not attended by the technological support, as well of others that may be useful in future designs. For this reason, some parts of the previous chapter may be repeated here, while others will be changed or added.

5.4.1 Classes

This HCI ontology for SAIL environments has its instances distributed into four classes: 1) Entity; 2) Device; 3) Graphical Interface; and 4) Interaction. Next, I will describe the basic characteristics of each of these classes.

5.4.1.1 Entity

Entities are the different types of actors in the system: Learners, Groups, Educators, and the Knowledge Base. The entities fulfill different roles, which will be described later, and interact through the graphical interfaces supported by the different devices.

5.4.1.2 Device

Devices are the hardware component of technology support. The definition of the type of device for each function or stage of a learning design has a direct impact on the scripting of activities and the design of graphical interfaces. For example, the use of mobile devices may be critical to allow the free movement of learners through the environment, but their smaller screen size may cause limitations to GUI design.
5.4.1.3 Graphical Interface

Graphical Interfaces are the software component of the technological support. Graphical Interfaces should be designed to facilitate the various types of entity interactions, considering the limitations of each type of device and exploiting its resources to the maximum, to support the scaffolding of the inquiry process towards the learning goals.

5.4.1.4 Interaction

Each action or task that the entities must perform through technology support will be classified as an Interaction. Thus, interactions are the different functions that the system must support. When organized and sequenced in different ways, a small repertoire of interactions can give rise to a virtually unlimited number of activities and inquiry dynamics.

5.4.2 Instances

5.4.2.1 Knowledge Base

Class: Entity

A pedagogical component central to the KCI model is the collaborative construction of a knowledge base, both as resource for and product of learners' inquiry (Slotta, 2013). Here, Knowledge Base is the instance of HCI design that corresponds to this pedagogical component. Such central role in the pedagogical model confers to this instance some characteristics quite different from the other instances of the entity class. The most obvious of these differences is that the Knowledge Base is the only entity that does not correspond to a human agent, or group of humans, but to a computational component. In this way, this instance does not interact intelligently with others; however, it should still be considered an entity, as it responds to the interactions of other entities, and affects their actions.
5.4.2.2 Educators

Class: *Entity*

This framework is intended to be generic enough to support a wide variety of designs. Thus, this ontology seeks to adopt less restrictive definitions for its instances. In this way, the educators entity covers any actor who contributes to planning and coordinating the learning experience. That means that a student may assume this role in communities that do not have a formal teacher, or even receive from a teacher the assignment to do so, or to assist them.

5.4.2.3 Learners

Class: *Entity*

Learners are any instance that is engaged in collective inquiry with the goal of achieving learning goals. In horizontal communities or communities with shared or rotating leadership, teachers can occasionally take on this role.

5.4.2.4 Groups

Class: *Entity*

Groups are any instance in which more than one learner behaves as a single entity. It can range from a pair of learners to an indeterminate number of learners working on the same task or performing the same action. It can be made of various smaller groups. A design can even consider a whole class as a group of individual learners or a group of groups in activities in which it behaves atomically.

5.4.2.5 Large Displays

Class: *Device*
Large Displays such as SmartBoards, TVs, or computer monitors can support interfaces intended to display information at a distance, or to be used by a group.

5.4.2.6 Computers

Class: Device

Computers are flexible enough to be used by educators, individual learners or small groups.

5.4.2.7 Handheld Devices

Class: Device

Handheld Devices will usually vary from smartphones to tablets. Its great versatility allows them to be used both for access to the Knowledge Base or other sources of information, as well as for producing information in the form of text or multimedia, through its photography, video and sound resources. In addition, their sensors can be used to take measurements or obtain other information from the environment, and their telephony data reception capabilities allow them to access the Internet outside the classroom.

5.4.2.8 Wearable Devices

Class: Device

Wearable Devices is an instance that comprises a wide range of devices, such as smartwatches, smartphones, and virtual reality headsets. They can be used to access information, introduce new forms of communication between entities and produce information through sensors.

5.4.2.9 Educator Interface

Class: Graphical Interface
An Educator Interface can be developed to provide educators with support for inquiry scaffolding and enactment orchestration, and for monitoring and assessing the progress of the community and each learner toward learning goals. Thus, the Educator Interface can support the formalization of learning goals and expectations, Knowledge Base modeling, creation and management of groups and activities, communication with other entities, etc.

5.4.2.10 Individual Learner Interface

Class: *Graphical Interface*

An Individual Learner Interface can be used through Computers, Handheld Devices, or some Wearable Devices. Learners use an Individual Learner Interface to individually add information to the Knowledge Base, and to access and manipulate information added by themselves, other learners, educators, groups, or that are generated automatically by the Knowledge Base. Learners can also use an Individual Learner Interface to communicate with other entities.

5.4.2.11 Group Interface

Class: *Graphical Interface*

A Group Interface supports interactions in which a group acts synchronously or atomically. This can include chats, video conferences, brainstorming sessions, collaborative text editing, etc.

5.4.2.12 Knowledge Base Representation

Class: *Graphical Interface*

A Knowledge Base Representation can be developed to display the status of the construction of the knowledge base, or to distribute information from the knowledge base that might serve as a resource for inquiry. It can display analytics that quantify the content already accumulated in the knowledge base, or to share information that may be useful to other instances.
5.4.2.13 Social Representation

Class: Graphical Interface

A Social Representation displays information about the learning community, or part of its members. It may serve to display analytics that quantify individual or collective progress toward learning goals, or information about each entity's functions in the collective inquiry.

5.4.2.14 Creating representation of personal identity (social profile)

Class: Interaction

Learners and educators can create representations of their personal identity to enrich social interactions. This may include their name or alias, personal information, avatars, pictures, or symbols (Figure 16).

![Figure 16. Learners can add their names and set an avatar.](image-url)
5.4.2.15 Defining and informing learning goals

Class: Interaction

Educators can formalize learning goals and expectations, allowing learners to be aware of them and the system to be able to measure and inform progress towards them.

5.4.2.16 Modeling the knowledge base

Class: Interaction

Educators can model the knowledge base by predefining hierarchies, relationships, and categories of information that will be contributed by other entities.

5.4.2.17 Creating tasks and activities

Class: Interaction

The system can give educators autonomy to create tasks and activities without need of support from programmers and technicians. Through a form, educators can define what should be done, who should do it and what is the due time, while the system is in charge of distributing the task to the right entities at the right time.

5.4.2.18 Grouping and / or sequencing tasks and activities

Class: Interaction

In addition to creating tasks and activities, educators can group and sequencing them to compose complex activities involving various interactions.
5.4.2.19 Controlling activity flow

Class: Interaction

Educators can remotely pause and resume the sessions in Individual Learner Interfaces or Group Interfaces (Figure 17) or can send less disruptive notifications that support orchestration.

Figure 17. A switch allows educators to individually pause or resume the activity of each group. A gray board indicates paused activity.

5.4.2.20 Creating groups

Class: Interaction

Educators can group entities or create empty groups for entities to join (Figure 18).
Figure 18. Educators can define a name to an empty group and send keys that allow entities to join it. Educators can also set permissions for group members.

5.4.2.21 Setting access permissions

Class: Interaction

Educators can manage other entities' permissions, allowing or preventing them to perform certain interactions (Figure 18).

5.4.2.22 Including and excluding learners in groups (and groups in larger groups)

Class: Interaction

Educators can manage the composition of existing groups, adding or excluding entities (Figure 19).
5.4.2.23 Requesting inclusion and exclusion of learners into groups

Class: Interaction

Alternatively, learners may request their inclusion or exclusion from groups, pending approval from educators.

5.4.2.24 Approving or rejecting requests for inclusion and exclusion of learners into groups

Educators can approve or reject requests for inclusion or exclusion into groups.

5.4.2.25 Creating representation of group identity (group profile)

Class: Interaction
A group can create representations of their identity to enrich social interactions. This may include their name or alias, group information, avatars, pictures, or symbols.

5.4.2.26 Adding information to the knowledge base

Class: Interaction

Adding information to the knowledge base is the most fundamental interaction in the system. On multiple occasions, entities will be asked to contribute data, information, evidence, theories, ideas, questions, or previsions. The basic design solution for this type of interaction is composed of text fields, usually with a button to attach multimedia content (Figure 20). That way, entities could photograph or record video or audio and attach that material to their contributions.

![Figure 20. Entities can add information to the Knowledge Base.](image)

5.4.2.27 Adding metadata

Class: Interaction
Learners, educators, or groups can add metadata on content, such as tags, categories, or classes (Figure 21).

Figure 21. Entities can apply tags to information. They can also archive or delete information.

5.4.2.28 Accessing information provided by educators, learners, or groups

Class: Interaction

Entities can access information provided by others (Figure 22).
Figure 22. A single interface shows a list of resources provided by educators and information provided by learners.

5.4.2.29 Accessing information automatically provided or organized by the system

Class: Interaction

Entities can access information automatically generated.

5.4.2.30 Relating information

Class: Interaction

Entities can relate information (Figure 23).
Figure 23. Learners can choose two pieces of information they want to relate and offer a reasoning.

5.4.2.31 Searching information

Class: Interaction

Entities can filter or search information (Figure 24).
Figure 24. Entities can use drop down menus or tags to filter the kind of information they want to access.

5.4.2.32 Editing information

Class: Interaction

Entities can edit pre-existing information (Figure 25).
5.4.2.33 Archiving information

Class: Interaction

Entities can archive information that is not currently useful but must be preserved (Figure 21).

5.4.2.34 Deleting information

Class: Interaction

Entities can permanently delete information (Figure 21).

5.4.2.35 Accessing edit history

Class: Interaction
Entities can access the edit history, to evaluate their evolution or restore previous stages.

5.4.2.36 Discussing information

Class: Interaction

Entities can discuss information in comments areas (Figure 26) or forums.
Figure 26. A nested comments area allows entities to discuss on the information and reply on each others comments.

5.4.2.37 Voting, validating, recommending, endorsing, ranking, rating information
Class: Interaction

Entities can attribute value to information.

5.4.2.38 Sending notifications about system changes
Class: Interaction

Educators or the Knowledge Base can notify entities about system changes, such as adding, deleting, and editing information, tasks, learners, and groups.

5.4.2.39 Managing the reception of notifications
Class: Interaction

Entities can manage the reception of notification, by following or unfollowing learners, groups, or certain categories of information.

5.4.2.40 Assessing and providing feedback on tasks, activities, and information
Class: Interaction

Entities can assess and provide feedback on tasks, activities, and information.
5.4.2.41 Tracking progress

Class: Interaction

Entities can track their progress in activities, sequences of activities, or toward the learning goals (Figure 27).

Figure 27. A progress bar shows that the student completed 10% of the task.
Chapter 6
Conclusion

The learning environment described in this thesis has been iteratively improved and has offered increasingly broad and solid support to KCI curriculum. The SAIL architecture, which provides the basis for the development of technological support to KCI, has also received new iterations that increase its capacity to support the future development of new environments and applications. This research fits into the process of enhancing such technologies, contributing to the general understanding of the role of HCI design, and particularly of GUI design, in this effort.

The ontological analysis of WallCology HCI identified some gaps in the technological mediation to the inquiry activities, which were supplied through interactions not mediated by the CK environment. This thesis does not suggest that such interaction types should be abolished, nor does it recommend that all the interactions that comprises an inquiry process must necessarily be mediated by a technological environment. However, the research contributes to expose all the possibilities of mediation that SAIL-based learning environments can offer, informing the process of learning design and contributing for the decisions about its implementation to be based on pedagogical adequacy, not on technical capacity.

By extending its HCI ontology to cover a wider range of interactions than has been so far demanded by KCI curricula, and offering a set of interface design principles and implementation guidelines, this research builds an HCI design framework that contributes to technological innovations in the context of this pedagogical approach. In addition, this framework contributes to the improvement of the control of the research environment, reinforcing the consistency of interface design and, consequently, reducing the possibility of "contaminants" being introduced within research designs.

It is important to emphasize that the ontological construction process is iterative and thus the framework offered by this research is open to future (and inevitably necessary) extensions and improvements. The field of HCI is by nature based on innovation. New technologies that constantly emerge offer new possibilities for human-computer interaction that might be exploited in learning environments. In addition, the framework scope could be expanded, including
interfaces for learning analytics, georeferencing and use of sensors, distributed computing, progression tracking extended to multiple curricular units, and others.
References


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