Evaluating Group Interaction and Engagement using Virtual Environments and Serious Games for Student Audiences in Informal Learning Settings

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Abstract

Museums are rich and complex learning experiences, using a variety of interactive approaches to engage their audiences. However, the largely unstructured nature of free-choice learning calls for alternative approaches that can effectively engage groups of school age students with diverse cultural backgrounds. In these informal learning spaces employing digital content, classroom-size student groups do not get adequate exposure to content and if they do, it is either through individual interactions with digital exhibits or in a passive style instruction offered by a museum docent to the whole group. This research aims to identify which elements of collocated group collaboration, virtual environments, and serious games can be leveraged for an enhanced learning experience for small and large groups of middle school students.

We created a conceptual framework based on the Contextual Model of Learning in museums (John H. Falk & Dierking, 2000) and the most effective educational elements of Virtual Environments (VEs) and Serious Games, in order to increase engagement and social presence and facilitate learning. We then developed C-OLiVE (Collaborative ORchestrated Learning in Virtual Environments), an interactive virtual learning environment supporting group collaboration, which we used as a testbed to respond to our research questions. Our overall hypothesis is that synchronous, collocated, group collaboration will afford greater learning and an improved game experience compared to the conventional approaches used in these spaces so far.

We ran three experiments and a case study with 790 students in private and public middle schools, summer camps, and museums both in the US and in Greece. Findings partly supported our hypothesis, mainly during our small group interaction experiments, in which simultaneous interaction of students was found to be associated with increased learning. Guidance of a passive experience was effective in facilitating the more cognitively challenged group of students in a Greek museum. Our audience interaction studies revealed increased retention of information two days after the game. Agency was found to significantly predict learning in all our studies. Engagement and social presence were mostly correlated with higher levels of involvement and agency in the game.
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General Audience Abstract

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We created a conceptual framework based on a theoretical model from museum studies, called the Contextual Model of Learning, and the most effective educational elements of Virtual Environments (VEs) and Serious Games, or learning games, in order to increase engagement and social presence (i.e., the feeling of interconnectedness between participants) and facilitate learning. We then developed an interactive virtual learning environment supporting group collaboration, which we used as a testbed to respond to our research questions. Our overall hypothesis is that synchronous, collocated, group collaboration will afford greater learning and an improved game experience compared to the conventional approaches used in these spaces so far.

We ran three experiments and a case study with 790 students in private and public middle schools, summer camps, and museums both in the US and in Greece. Findings partly supported our hypothesis, mainly during our small group interaction experiments, in which simultaneous interaction of students was found to be associated with increased learning. Guidance of a passive experience was effective in facilitating the more cognitively challenged group of students in a Greek museum. Our audience interaction studies revealed increased retention of information two days after the game. Agency (or level of control) in the game significantly predicted learning in all our studies. Engagement and social presence were correlated with higher levels of involvement and agency.
To my mother, who taught me to inquire
To my wife, who supported all my inquiries
To my son, the master of inquiry
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Chapter 1

Introduction

It is widely acknowledged that museums can provide ample opportunities for group learning, exploiting children’s exposure to digital technologies like computer games (Sefton-Green, 2004). However, in many cases these experiences are impeded by the restricted and structured type of school group visits, deprived of the optimal learning opportunities afforded by these spaces. That is not to say that unrestricted visitor choice is a panacea to informal learning, as totally loose interaction with the museum content can impede learning. Sue Allen, from the Exploratorium in San Francisco, discusses the need for studying the impact of interactivity on learning, through extended engagement and self-directed inquiry, particularly for multiple users, when using science museum exhibits (Allen, 2004); or any such experience. Guided by this prompt and my personal experience described below, the overarching goal of this study is to understand the impact of group interactivity on learning in collaborative game play, during museum visits.

1.1 Motivation

Having worked for more than a decade in, what was called, an interactive museum in Greece, I developed for and observed interactions of groups in an informal setting, with the main objective to learn something in an entertaining manner. “Hellenic Cosmos” is a cultural center in the form of an interactive museum that uses state-of-the art technologies, such as touch panels, virtual reality projections, and a digital dome theater, as aids for the dissemination of Hellenic history. The main audience of the museum is school classrooms, constituting 80% of the total visitors, with families having school aged children being the second most popular target audience.

1 Hellenic Cosmos aims to fulfil the mission of the Foundation of the Hellenic World, which involves the dissemination of Hellenic history and tradition using new technologies.
As such, this museum (as many others all over the world) has developed a variety of educational programs in order to address the increased demands of school group visits. This involves in most cases having a dedicated museum educator provide a demonstration of (digital) exhibits, or when interactive technologies are in use, have full control of the application limiting visitors to a largely passive experience. Figure 1-1 depicts two such instances from Hellenic Cosmos, where the museum educator is coordinating/facilitating students’ learning activities by controlling a computer game (left) or navigating through a virtual world (right).

Figure 1-1. Interactive experiences in Hellenic Cosmos facilitated by museum educators; (left) using a computer board game about history and (right) navigating through a virtual reconstruction of an ancient site (images courtesy of the Foundation of the Hellenic World).

However, what is even more common in these spaces is for students to individually interact with digital exhibits, such as computer games and info kiosks, with minimal to no meaningful or coordinated social interaction (see Figure 1-2).

Figure 1-2. Students playing with computer games (left) and info kiosks (right), during school group visits at the Hellenic Cosmos cultural center (images courtesy of the Foundation of the Hellenic World).
1.1 Motivation

It is indeed a common practice of existing game designs in museums to be limited to personal and isolated experiences, not taking full advantage of the great potential of social interaction and collaboration with other museum goers (Hsi, 2003), or even between group members. Nonetheless, this need not be the case, as technological advancements in museums and science centers have increased considerably over the years, with many such spaces adopting high-end equipment (e.g., wall-tiled displays, large projection surfaces, and even digital dome theaters), capable of accommodating and engaging large audiences. As an example, Hellenic Cosmos employs a CAVE\textsuperscript{2} accommodating 10 people and a full digital dome theater with a capacity of 132 people, both with real-time stereoscopic rendering capabilities.

![Group of students interacting with stereoscopic displays, where only one is having control of the environment; (left) a virtual tour of an ancient city using an immersive display and (right) a virtual exploration of Byzantine costumes in the CAVE (images courtesy of the Foundation of the Hellenic World).](image)

As has been noted, such technologies combined with the enhanced capabilities of converging media forms, such as games and virtual environments (VEs), provide ample opportunities for “learning through social interactions in different contexts” (de Freitas & Griffiths, 2008). At the same time, cultural heritage games are building on advances made in entertainment games technology, such as computer graphics, human computer interaction, artificial intelligence, and virtual and augmented reality (Anderson et al., 2010). However, the educational potential of these technologies and media forms for group learning have been largely unexplored, making this the overarching goal of our research.

\textsuperscript{2}CAVE (CAVE Automatic Virtual Environment) is a virtual reality system using large projection walls surrounding the user, allowing full immersion of a group of people in synthetic worlds (Cruz-Neira, Sandin, & DeFanti, 1993).
Additionally, an identified problem in existing education approaches is their inability to keep up with the demands of the “millennials.” Indeed, this generation of learners, or “digital natives” as they have been characterized (Prensky, 2001b), demand a significantly different instructional approach than the one offered by traditional pedagogy. Since reform of formal education is a challenging and time-consuming process, it makes sense to start by incorporating these novel educational practices in informal learning. A significant requirement for this reform is that “learning can and must become a daylong and lifelong experience,” occurring “not only in schools, but also in homes, community centers, museums, and workplaces” (Resnick, 2002). This type of indirect, spontaneous (or informal) learning can be encouraged at home (or public spaces like museums) by having children actively make connections between the game scenario and the real world (Gee, 2003). Simulation games (de Freitas, 2006) and virtual reality (VR) applications (Winn, 2005) are both considered appropriate means for enhancing authentic experiences in an entertaining and motivating manner well suited for children, which supports our choice to use their combination in our research.

Furthermore, collaborative learning has been connected with increased learning gains in many different situations, especially in computer-mediated collaboration/cooperation (Dillenbourg, 1999; Slavin, 1995; Stahl, 2006). Typical experimental setups involve two, and much less often three or more, students working together on common problems or competing against each other as teams, either collocated or distributed in different places, using different types of media (e.g., telecommunication software, collaborative learning platforms, commercial and custom games) and technologies ranging from desktop computers to large-scale immersive VR setups. However, most research has focused on either formal learning environments such as classrooms, or controlled experimental settings, especially when specialized hardware is involved. Thus, we have identified a need for investigating the learning benefits of a larger group of students collaborating using a computer simulation game, inside an informal learning setting.

Collocation of students playing games in a museum space brings also questions about the impact of their social gaming experience on the learning outcome. As emphasized by many scholars (Adams & Moussouri, 2002; Jensen, 1998; Kiousis, 2002; Steuer, 1992) social interaction, or social presence, is a key factor in the design of successful interactive systems. This is especially the case in interactive entertainment, such as 3D computer games, where players indulge far more in the collaboration or competition with other humans than with computer-
generated players (Joiner, 1998). Yet one more goal of the current research is to investigate if the multiplayer opportunity offered by collocated interactive experiences, can promote the feeling of social presence and enhance the game experience, enabling the members of an audience (i.e., the players) to engage in complex social relationships, also facilitating their learning. Such instances of what we call audience interaction for learning are pivotal to this research, but have scarcely been examined by researchers (the few available examples are being reviewed under Section 2.2.4.3).

Finally, most theories of instruction, whether formal or informal, are dissociated from the sociocultural profile of the learners. Therefore, there is a need to provide more options to students to choose their own way of learning; one that is designed to fit their sociocultural background (Pinkard, 2004). This need is even more imperative in museum spaces, visited by a diverse audience with different levels of prior knowledge, different interests and expectations from the visit, and different cognitive and game playing skills, all of which affect the experience and eventually the learning outcomes. Visitors, acting as learners, with different skills and backgrounds have the unique chance to collaborate in activities and discussions, in order to arrive at a shared understanding of the truth in a specific field (Duffy & Jonassen, 1992). Hence, a secondary aim of this research is to investigate the impact of culture and prior knowledge on students’ engagement with a discovery learning environment in a museum setting.

1.2 Concept Definitions

In this part we would like to clarify some terms and concepts that are being used in various ways in the literature, in order to set the right expectations for the scope of this research. These terms are being used extensively throughout our work, so this section can act as a reference about their meaning and how they should be interpreted in the context of this dissertation.

i. Level of Interactivity

Interactivity has been used extensively in research coming from a diverse set of disciplines and is thoroughly discussed in Section 2.2. In human-computer interaction research it mainly refers to the exchange of actions and feedback between the human and computer agent(s). However, in the context of our research, interactivity also encompasses the degree of collaboration between the participants enabled by the technology. A low level of interactivity indicates that users are mostly
passive with few (if any) opportunities for interaction, not only with the computer environment but also between themselves. On the other hand, a high level of interactivity implies that participants have greater control over the unravelling story (i.e., the game story, in our case), but also simultaneous collaboration between participants is encouraged by the system. We call this type of coordinated action between group members “orchestration” and elaborate on its expected impact on learning in the corresponding Section 3.1.2.

ii. Level of Agency

Agency is mainly a concept from cognitive science and refers to the subjective awareness that one is initiating, executing, and controlling one's own volitional actions in the world (Jeannerod, 2003). In general it refers to the sense of controlling our own fate and actions. In a gaming context, which is how we are using it in this work, it is the degree to which a student-agent can control and have an impact on what is happening in the virtual world. To differentiate between the technological agency (i.e., the degree of control using interaction devices) and the subjective experience of impacting the outcome of the game, we will use the term “sense of control” to describe the latter. We still consider that the sense of control/agency is a significant component of an interactive experience, especially for a group of people, this is why we will discuss its implications on audience interaction in the corresponding chapter.

iii. Level of Involvement

Involvement and engagement have been used interchangeably by some researchers to describe psychological immersion in a story, task, event, or activity; e.g., audience involvement was used in communication studies for non-interactive entertainment-education (Sood, 2002). In our research we discriminate between engagement as the psychological construct, which does not necessarily demand agency, and involvement as the actual active interaction with a technology-mediated task. Audience involvement in our work indicates a group of students meaningfully interacting with the game, by either having direct impact on the virtual environment or assisting more active agents (i.e., other students) to complete the necessary tasks.

Considering the aforementioned distinction, we provide below the operational definition of involvement used in our work (where $n$ is the number of interactions during the experience):

\[
Inv = time_{1\text{agency}_1} + time_{2\text{agency}_2} + \cdots + time_{n\text{agency}_n}
\]
According to the formula above, the level of involvement with a game equals the weighted average of the number of interactive episodes during the lifetime of the experience, multiplying the duration of each interaction by the degree of control or agency given during that interaction. In other words, the more control someone (or a group of people) has in the game or digital experience and for a longer period of time, the higher the perceived level of involvement. As an example, an individual player in a first-person shooter game experiences a very high level of involvement, due to his sustained agency in the game (i.e., continuous episodes with high level of control). On the other hand, a computer chess game provides a much lower involvement level because the players’ interactive episodes are shorter and are interrupted by longer intervals of strategic thinking and the opponent’s turn to think/interact.

1.3 Research Questions

Museum education experts have argued that learning in museums is contingent on visitors’ prior knowledge, interests, beliefs, expectations, degree of interaction with the exhibits/artifacts, within-group sociocultural mediation, and facilitation by others (John H. Falk & Dierking, 2000); some of these conditions can be controlled while others can only be taken into account. Moreover, as suggested before, museums need not do much more than provide a high quality experience that engages prior knowledge in an achievable intellectual challenge, and help visitors assemble the physical, intellectual, and social resources they will need to succeed (Csikszentmihalyi & Hermanson, 1999). Following such prompts and our motivation, the overall scope of this research is to harness the social interaction of students while using a collaborative computer game during a relaxed (i.e., informal) museum visit, and assess the assumed enhanced social presence and game experience, as well as their impact on learning gains.

In trying to evaluate the aforementioned objective of achieving an enhanced group learning experience in an informal education context, we will address the following research questions:

RQ1: What is the effect of the level of interactivity on learning in a gaming, collaborative VE (CVE) for more than two collocated participants?

Many instructional theories and research efforts focused on the potentially positive impact of interactivity on learning, in many different contexts. Similarly, computer-mediated collaborative learning has proven to be effective in many educational settings (either formal, such as classrooms,
or during controlled experiments), mainly between two participants. Based on such prior work, we plan to advance understanding on how the level of interactivity affects learning, within small and large groups working together while playing a 3D computer game.

**RQ2: What is the interplay between level of interaction, game experience, social presence, and learning during within-group collaboration in physical space?**

Some elements of game experience, such as engagement or immersion and flow, have been connected with students’ increased motivation and learning outcomes. Some others (e.g., competition and challenge) have either received mixed comments about their educational efficacy or have been rarely examined in the context of learning. Social presence, involving the behavioral and psychological involvement of players with their peers, is such a measure that its connection with learning has not been investigated enough. Our research aims to deepen our insights on how all these measures are connected in the context of collocated collaborative play. E.g., does increased social presence contribute to learning outcomes? Does more interaction with the game increase social presence and/or game experience?

**RQ3: What is the effect of culture, prior knowledge, and the style of information presentation (facilitated or not) on learning using a gaming CVE in a museum-type setting?**

Sociocultural theories of learning have emphasized the importance of the cultural background of learners, stressing how this affects learning styles and preferred ways of instruction. However, most research efforts focused on culture’s effects on cross-cultural communication or collaboration and not the differences across cultures. Additionally, prior knowledge and the degree of guidance during instruction are widely believed to be decisive factors of learning, in many cognitive theories. Thus, we would like to investigate how all these factors can affect not only learning, but also game experience and social presence, within a free-choice learning space, by comparing these measures across two significantly different cultures in terms of education.

**RQ4: How does the level of involvement of a large audience of students affect game experience, social presence, and eventually learning during collocated collaboration?**

During school group visits in museums there are ample opportunities for social interactions between students while using interactive exhibits. Although the level of control over the flow of information has been shown to affect positively learning in museums, but also during game play
and while being immersed in virtual environments, it has rarely been investigated with a larger group. Thus, we would like to evaluate new ways of large group interaction in the context of informal learning and better comprehend how the level of involvement of an audience with a digital game can affect their game experience, social presence, and eventually learning.

1.4 Hypotheses

In this section we present the main hypotheses of the previously presented research questions. Our hypotheses derive mainly from prior research and our own experiences of building and

**H1: Higher levels of interactivity will afford greater learning gains.**

Students having equally increased control of the game environment will probably reveal greater learning gains, as measured from the score difference of a pre/post-experiment quiz. We expect this result based on previous research revealing the positive impact of interaction on learning.

**H2: Higher interaction levels will increase game experience and social presence, positively affecting the learning outcome.**

This is a complex question with many sub-questions pending validation. Hence, we constructed a path model\(^3\) revealing our main hypotheses based on prior research on games, motivation, virtual environments, and learning, as well as our own experience working on game-based learning for children in a museum. The lines indicate our hypotheses and the plus (+) signs indicate a positive correlation between the constructs. *Presence* refers to the feeling of “being” inside a synthetic world and has been shown to contribute to learning in research on virtual reality for education; it was included here for reasons of completeness, although it is not formally taken into account in our research questions.

---

\(^3\) A path model is a statistical method for analyzing the interrelationships between variables and is commonly used in social sciences research.
Chapter I – Introduction

Figure 1-4. The path model for validating RQ2; hypotheses are indicated using the lines, with the plus (+) sign indicating a positive correlation (e.g., interaction level will positively affect game experience).

**H3a: Prior knowledge will be a contributing factor to learning.**

The impact of prior knowledge on learning has received contradictory comments from cognitive science researchers. Although it is intuitive to assume that having prior knowledge on the domain can facilitate learning, in actuality prior knowledge might impede learning if the already constructed mental models are not well-established or erroneous, demanding increased cognitive effort to alter misconceptions (Roschelle, 2007). In our case, our assumption is based on the fact that we will compare samples from two populations with significantly different exposure to the domain knowledge.

**H3b: Cultural differences will affect the learning outcome in an unpredictable manner.**

Differences between cultures are generally affecting not only learning styles but also societal norms. This leads us to believe that students participating in our experiments with different cultural backgrounds will not only differ to the preferred ways of acquiring information, but will also express essentially different behaviors during social interactions, both of which might facilitate or impede learning.
1.4 Hypotheses

H3c: Cultural differences will not affect game experience and social presence.

Since the population would be homogenous as far as age is concerned between the two cultures, we expect to have no significant differences in the students’ engagement with and enjoyment from playing the game in the company of friends. We are basing this hypothesis on research related to game-based learning conducted across different counties/cultures, but also from observations of children using technology socially in Greece and the United States.

H3d: Facilitation will help students with lower cognitive abilities and/or weaker game playing experience.

Unguided instruction has received considerable criticism over the years, however some situations (such as the informal learning paradigm studied here) call for discovery learning practices. Based on the arguments against fully unguided instruction and our observations of students game-playing attitudes in public (i.e., during school visits in a museum), we hypothesize that facilitation will prove beneficial only to students who are either cognitively challenged by the game and/or are less confident in controlling the game, especially in public.

H4a: Sustained involvement of a student audience will increase game experience, social presence, and eventually learning.

It is very common during museum school visits to have a large number of students becoming the audience of the few who interact with technology. Our hypothesis is that by actively involving those students in the game we will improve their overall (game) experience, they will feel more connected with each other and with their (playing) peers, and will eventually reveal greater learning gains.

H4b: Students with direct agency in the game will enjoy the game more, but will not necessarily learn more than the audience.

Besides the large amount of evidence revealing the positive impact of (game) control on learning, there have been quite a few studies and theories that indicate that increased demands unrelated to the actual learning might overflow the cognitive processing capacity of the learner (Sweller, 2005). Consequently, depending on the cognitive and game-playing competency of the active players, they might learn more, equally, or less than the less engaged audience.
Chapter I – Introduction

1.5 Research Overview

In this section we briefly describe the steps we took for carrying out the current research. After conducting a thorough literature review about learning theories and interactivity, and their application in computer-supported collaboration, games, and virtual environments (Chapter 2), we describe the conceptual framework and testbed application that we developed to respond to our research questions (Chapter 3). Then we present the studies we conducted to validate our hypotheses, including two experiments with small groups of students playing our game (Chapter 4) and one larger experiment and a case study during which we were testing the audience interaction paradigm suggested in our framework (Chapter 5). Finally, we conclude with a summary of findings and lessons learned, presenting a list of design guidelines and suggestions for future work (Chapter 6). The main products of this dissertation work are presented below in a little more descriptive manner.

i. Background and Related Work

Initially, we present a review the most popular learning theories and how they have been used over the years to disseminate knowledge, giving special attention to technology-enhanced learning. Then, we scrutinize interactivity, as the common denominator of most computer-mediated collaborative approaches, especially for learning. Last, we investigate the involved technologies in the proposed integrated schema for (large) group interaction, more specifically games and virtual environments, especially for use in collaborative and informal education contexts. During this process, we identified the gaps of existing research and used the theoretical perspectives of the related work being reviewed to inform our conceptual framework, which we suggest has the potential to fill these gaps.

ii. Conceptual Framework

In the next step we describe the development of our conceptual framework, which was used to validate the research questions presented before (see Section 1.3). The framework borrowed concepts from learning theories, especially about contextual learning in museums, and elements of games and virtual environments that have been shown to contribute to knowledge acquisition. The conceptual framework is presented and described in detail under Section 3.1.
iii. Testbed Application

In order to test the main hypotheses of our research (see Section 1.4), we developed a testbed application that we are going to use with groups of middle school students. The application domain chosen was deemed appropriate for enabling the model of simultaneous collaboration of a group of three (or more) students, which we hypothesize, can facilitate group learning in a museum. It also encompasses all the elements of simulation games and virtual environments proposed by our conceptual framework, which will allow us to check its viability. A detailed description of the testbed application design is included in Section 3.3.

iv. Experiments & Case Study

The next step was to design and conduct three experiments using variations of the testbed application that allowed us to respond to our research questions and test our hypotheses. A final case study allowed us to inform our testbed with all lessons learned and test it in a real-world setting.

Experiment I: Evaluating the effects of orchestrated, game-based Learning in virtual environments for informal education

The aim of the first study was to understand the impact of interactivity on the game experience and learning of a small group of students playing a game (i.e., address RQ1 and RQ2). The study was conducted with US middle school students split in groups of three in a controlled environment, either watching someone play the game or playing the game using game controllers. We found that tripartite collocated collaboration was associated with improved learning benefits over passively watching someone play a game, when also considering game experience and social presence measures (e.g., immersion, flow, challenge, positive/negative feelings, etc.) A detailed report of the design and results of this experiment is presented in Section 4.1.

Experiment II: Implications of culture and prior knowledge for a collaborative learning game in a museum context

The second study had the same goals as the first one (respond to RQ1 and RQ2), but also some additional ones related to RQ3. More specifically, we ran the study in an actual museum in Greece to increase ecological validity and also assess how the museum visit expectations might affect learning. Recruiting students from a different culture, with traditionally more exposure to the knowledge domain, allowed us to assess the effects of prior knowledge and interests on
the outcomes, but also compare results between cultures. Finally, we substituted the totally passive condition of the first study with a museum guide playing the game and facilitating students’ learning, in order to assess the impact of guided instruction in discovery learning settings. The results were mixed and are presented in detail under Section 4.2.

**Experiment III: Audience interaction for increased student involvement and learning, using games and virtual environments**

The third experiment was designed to involve a larger group of students in the game and eventually the learning process, mainly addressing RQ4. We varied once more the level of interaction, or involvement, of the participants and also measure game experience and social presence, and as such gained greater insights on RQ1 and RQ2, with a larger group. Two students had full agency in the game, as our fully interactive condition until now, and the rest of the classroom (i.e., the audience) got to intervene using iPad tablet devices. This experiment is presented in more detail under Section 5.2.

**Case Study: Applying design principles for the development of a simulation game for student audience interaction in a museum**

The findings from the previous three studies were used to inform the design of our game to be used in a museum. The goal of this case study was threefold: increase the ecological validity of our audience interaction scheme; incorporate the game in an informal education activity for students; and test and refine the design guidelines we set as a goal at the outset. The game was incorporated in an educational program we presented in a science museum, and an after-game activity was developed as a means to complement the game but also act as an assessment for learning. More details about the case study can be found in Section 0.

**v. Development of Design Guidelines**

Based on the findings and lessons learned of the three experiments and the case study, we developed a list of design guidelines for the use of large group interaction with simulation games and virtual environments for informal learning. Although our main motivation was to investigate how to better facilitate group learning in public spaces such as museums and science centers, these guidelines will hopefully help collaborative learning researchers to evaluate the requirements for effectively engaging a larger collocated group of (young) learners in the learning process, using state-of-the-art interactive technologies.
1.6 Expected Contributions

The benefits of this work derive from our approach on merging the gaming, VE technology, and museum worlds, for enhancing the visitor experience and learning gains of a large group of students. More specifically, this research is expected to help researchers/designers of collaborative virtual learning environments and digital museum exhibits:

- Get a better understanding of the effects of group interaction on game enjoyment and social presence, and how this can affect learning in collocated multi-user setups. This can mainly happen by using our conceptual framework and validating their design idea to identify elements of the technologies involved and the physical setup that can possibly increase the entertaining and/or educational value of their design.

- Identify the techniques that are most effective for eliciting enjoyment and supporting learning using digital games for large audiences. Such techniques can be based on the design of our game and can be adapted appropriately depending on other factors, such as number of people interacting simultaneously, target group, physical space, etc.

- Design successful interactive learning experiences for a collocated group by applying our design guidelines. Additionally, these guidelines can be used as an assessment tool to evaluate the cost-benefit ratio of applying game design for group learning in public spaces, such as museums and science centers.
Chapter 2

Background and Related Work

The inherently interdisciplinary nature of this research forces us to conduct a thorough investigation of the subjects involved, in order to acquire a better understanding of their definitions and ramifications. The main components comprising the integrated schema proposed in this study that require detailed analysis are: Interactivity, Collaboration, Serious Games, Virtual Environments, and the impact that all these have on facilitating Learning. Thus, the aim of this chapter is threefold. First, it constitutes a state-of-the-art review of the research work implemented on these intertwined fields, and the technological trends of their application areas. Second, it is an attempt to analyze the strengths and weaknesses of the underlying theories and used methods of these research fields in facilitating learning. Third, it is an endeavor to identify the differences and similarities of those practices compared to the current research.

At the end of this literature review the expected outcome is to have tracked down the deficiencies and gaps of contemporary research practices, and have extrapolated the assumed necessity for conducting this research. In order to achieve this, we will start by the definition of learning as the joining link of the aforementioned constituents of our study. Then, we will continue by defining each term and elaborating on how related work has tried to exploit its educational benefits. Eventually, the most eminent application examples of the integration of these terms will be reviewed, critiqued, and juxtaposed to the current research. Since these technologies are greatly overlapping, these examples will appear throughout the different sections, where we consider them to be more appropriate.
2.1 Learning

Learning is notoriously difficult to define. Abundant learning theories have emerged over the years, especially by psychologists, who have studied the psychological processes that allow humans to learn, and philosophers, who tried to identify the cognitive implications behind individual and social types of learning. Although there is no agreed explanation of how learning is achieved in humans, most of those theories have some similarities and common points which accounted for their integrative application in education. Furthermore, their unique attributes allow them to be applied more effectively in different contexts, application domains, and various educational settings (formal or informal).

Commencing with behaviorist theories of learning, we will scan through the cognitivist and sociocultural ones and explicate the way they have affected learning within those diverse educational settings. We will then have a brief discussion about the dimensions of educational theory, namely the perspective of education from the dichotomy of the learning theory and the theory of knowledge, as well as the type of learning that takes place in informal settings. Finally, we will look at how these theories have been exploited by technology throughout the years, in order to facilitate learning.

2.1.1 Theories of Learning

2.1.1.1 Behaviorist theories

According to behaviorist learning theories, learning occurs as a result of change in overt behavior. Skinner, one of the first proponents of behaviorism, stated that changes in behavior occur as a result of the individual’s response to external events (stimuli) happening in the environment (Skinner, 1953). Positive reinforcement is crucial in encouraging and re-evoking the desired behavior and, eventually, facilitating learning. By rewarding (reinforcing) the particular behavior (stimulus-response pattern), the individual is conditioned to respond correctly, thus the name operant conditioning was given to Skinner’s theory of learning. Negative reinforcement (punishment) is generally avoided, by forming the practice material (question – answer frames) in such a way that the difficulty of questions is controlled and the student can aptly supply the correct answers.

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4 A quite extensive reference list on learning theories can be found at: http://www.learning-theories.com/ [last accessed: October 2014].
Gagne (1985) believed that different types of learning and consequently different types of instruction are required for different learning outcomes. According to his theory, there are five major levels of learning: intellectual skills, verbal information, cognitive strategies, motor skills, and attitudes, although the focus of Gagne’s studies was mainly placed on the first one. Acquiring skills on each type of learning hinges on a diverse set of external and internal conditions (e.g., practice problem-solving as a means of developing cognitive strategies). Also, Gagne identified nine instructional events, or *conditions of learning*, and corresponding cognitive processes (in parentheses below) that guide the design of successful instruction: gaining attention (reception), informing learners of the objective (expectancy), stimulating recall of prior knowledge (retrieval), presenting the stimulus (selective perception), providing learning guidance (semantic encoding), eliciting performance (responding), providing feedback (reinforcement), assessing performance (retrieval), and enhancing retention and transfer (generalization).

Even earlier than Skinner and Gagne, at the outset of the 20th century, the Russian scientist Ivan Pavlov was the first one to have studied the role of behavior in learning, and is considered by many to be the father of behaviorism. His idea of “conditioning” as an automatic form of learning, has guided future research in psychology, despite the fact that his experiments were mainly conducted on animals. The influence of his work was of such significance, that even today the expression “Pavlov’s dog” is used to describe someone’s reflective behavior without using critical thinking\(^5\).

### 2.1.1.2 Cognitivist theories

Contrary to behaviorism, according to which learning is independent of the learner and a mere consequence of behavior change, *cognitivism* is a theory based on the belief that learning is absolutely learner-dependent and can only be explained by studying the cognitive functions of the learner. Cognitivists consider the mind to play a vital role in constructing knowledge, by describing mental functions as information processing models. Focus of the cognitivist theories is placed on the inner mechanisms of human thought and the process of knowledge acquisition, through the investigation of the relationship between our mental structures and the way they affect our physical actions.

Chapter II – Background and Related Work

The work of Jean Piaget on the cognitive development of children is probably one of the most notable cognitivist theories. Piaget (1973) identified four cognitive structures that correspond to a child’s development stages: sensorimotor (0-2 years), preoperational (3-7 years), concrete operational (8-11 years), and formal operational (12-15 years). Although the age span of every stage varies according to individual idiosyncrasies, our work is addressed to the last stage, during which thinking is rational but depends upon concrete referents. Learning (cognitive development) is facilitated by involving the student in engaging activities that demand constant adaptation to the environment, in terms of assimilation (using existing cognitive structures to interpret events) and accommodation (changing the cognitive structures in order to make sense of the situations encountered). Due to its basis on using cognitive structures to construct meaning, this theory is also called structural constructivism.

Another advocate of the constructivist theory is Jerome Bruner, who believes that learning is an active process in which learners construct new ideas or concepts based upon their past knowledge. By relying on their current cognitive structures, which provides meaning and organization to experiences, learners choose and transform information, construct hypotheses, and make decisions in order to “go beyond the information given” (Bruner, 1960). This type of learning is also called discovery learning, because the instruction is structured in such an initially simple, easily grasped, and readiness inductive manner, as to encourage students to participate in the activity and discover the taught principles by themselves.

The same principles guide the theory of philosopher and educator John Dewey, who perceived genuine experience as the cornerstone of effective learning. Although not all experiences are educative, it is incumbent that the learner is actively engaged with the world and not a passive recipient of knowledge which exist impertinent to prior experiences (Dewey, 1938). This constitutes one of the most fundamental fallacies of instructional methods, which presuppose some kind of prior experience on the subject matter on behalf of the students. Instead, learning should provide continuous activities eliciting motivation, present problematic situations stimulating thought, mobilize prior knowledge in dealing with those situations, induce and cause to develop self-discovered solutions, and afford opportunity for testing and validating those solutions through trial and error (Dewey, 1916).
Dewey’s ideas were enunciated under the title of *experiential learning*, whose first proponent was the famous psychologist Carl Rogers. Rogers (1969) distinguished two types of learning: the “meaningless” cognitive type (acquiring academic knowledge) and the significant experiential type (acquiring applied knowledge). The latter is the most pervasive and long-lasting type of learning, because it is self-initiated, demands personal involvement (emotional and intellectual), and is self-evaluated. This ‘learning by doing’ type is best facilitated when the student is actively engaged in the learning process, has control over the ways s/he can employ to deal with the practical, personal or social problems, and self-criticism and self-evaluation are considered more important than evaluation by others. Such type of learning we consider to be highly important for the current research.

David Kolb, another advocate of experiential learning theory, proposed four distinct learning styles which describe the learning preference of each individual: accommodating, diverging, converging, and assimilating (Kolb, 1984). He also defined the “circle of experiential learning” which applies to all humans and defines the learning style of each one of us. This four-stage learning cycle commences with a “concrete experience” (feeling) providing a basis for “reflective observation” (watching), which is assimilated and translated by “abstract conceptualization” (thinking), producing new implications for “active experimentation” (doing). Our individual learning style is determined by a combination of the method we choose to approach the encountered experience (watching or doing) and the way we choose to transform the experience (thinking or feeling). Kolb’s learning styles can be illustrated by the two-by-two matrix shown in Table 2-1.

<table>
<thead>
<tr>
<th>Concrete Experience (feeling)</th>
<th>Active Experimentation (doing)</th>
<th>Reflective Observation (watching)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accommodating</td>
<td></td>
<td>Diverging</td>
</tr>
<tr>
<td>Converging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstract Conceptualization (thinking)</td>
<td>Converging</td>
<td>Assimilating</td>
</tr>
</tbody>
</table>

*Table 2-1. Learning styles of Kolb’s experiential theory.*

Seymour Papert’s idea of *constructionism* is based on experiential learning, but also inspired by the constructivist learning theory of Piaget. According to the constructionist approach, learning is more effectively achieved when you engage students in the construction of meaningful
products through the use of tangible objects (Papert, 1993). Based on the constructivist theories of psychology, constructionism considers learning as a construction rather than as a transmission of knowledge, but also “attaches special importance to the role of constructions in the world as a support for those in the head, thereby becoming less of a purely mentalist doctrine.” (p. 143). The main difference between Piaget’s constructivism and Papert’s constructionism is that the former is mainly interested in the construction of internal stability (what Piaget calls assimilation) through the mental manipulation of symbolic artifacts, whereas the latter is focused on the dynamics of change (accommodation in Piaget’s words) by “diving into” situations rather than looking at them from a distance (Ackermann, 2001).

Besides Piaget’s and Papert’s constructivist approach to learning which considers intelligence as adaptation between stability and change, other theorists have provided insight on defining the way we learn. Maybe the most prominent one is Howard Gardner’s multiple intelligences, according to which each individual possesses seven primary forms of intelligence that define in a great degree the optimum way by which this individual learns (Gardner, 1983). These forms are: logical-mathematical, linguistic, body-kinesthetic, spatial, musical, intrapersonal, and interpersonal. Children should be encouraged to develop the forms of intelligence to which they are inclined, although assessment of abilities should measure all forms, not just the most common ones for school curriculum: logical-mathematical and linguistic. Informal settings, like museums and amusement parks, are suitable places for reinforcing the other—underestimated by formal education—forms of intelligence.

2.1.1.3 Sociocultural theories

Many of the aforementioned theories have included, more or less, the significance of social interaction in facilitating the learning process, like Gardner’s interpersonal form of intelligence. Also, more recent work by Bruner employed cultural psychology to interpret how individuals construct “realities” based on cultural narratives and symbols and cultivated through social interaction, as a pursuit for “the messy, ambiguous, and context-sensitive processes of meaning-making” (Bruner, 1996). His approach defies the assumption that the mind is simply a mechanism

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6 Quote drawn from the proposal titled ‘Constructionism: A New Opportunity for Elementary Science Education’ addressed to the National Science Foundation in 1987, retrieved on October 2014 from: http://nsf.gov/awardsearch/showAward.do?AwardNumber=8751190
of information processing and claims that knowledge is “intersubjective” rather than external or objective.

However, the pioneer of the social development theory is considered to be the Russian psychologist Lev Vygotsky, who studied the role of social transactions in child development and education. One of the most radical views of Vygotsky (1978) was that children learn more effectively while their cognitive status resides within the “Zone of Proximal Development” (ZDP), which can be defined as the space between the knowledge acquired by individual effort and the knowledge acquired by the guidance of a tutor or collaboration with more capable peers. The ZDP is closely related to the teaching method of scaffolding, during which the instructor (or a more skilled person), adapts the level of guidance according to the perceived degree of the child’s current performance. Moreover, Vygotsky believed that language is leverage for effective learning, especially for the child’s social development, by means of enabling thought to develop and be expressed through words (Vygotsky, 1986).

One of the most influential sociocultural theories is the social learning theory of Albert Bandura (1977), which emphasizes the importance of observing and modeling the behaviors, attitudes, and emotional reactions of others. Key ideas of Bandura’s theory are that people learn through observation, that intrinsic reinforcement (e.g., pride, satisfaction, sense of accomplishment) is important to learning, and that—contrary to the behaviorist beliefs—learning does not necessarily account for change in behavior. The modeling process of observational learning includes the following steps: paying attention to the modeled behavior, retention of information given, personal motivation to imitate the behavior, and finally, reproduction of the observed behavior. Further practice of the learned behavior leads to improvement and skill advancement.

Based on the theories of social learning, situated cognition and the derivative cognitive apprenticeship model, suggest that skills can be acquired by participating in authentic contexts and by collaborating with experts and peers in these contexts (J. S. Brown, Collins, & Duguid, 1989). The basic idea is that the cognition involved in getting from the problem to its solution cannot be isolated from the context within which both problem and solution are situated. This theory argues that the limited educational value offered by classrooms is due to their inability to provide the contextual features that allow authentic activity. Learning is a process of enculturation, partly supported by social interaction and the circulation of narrative, which are most effectively
achieved through **group interaction** and **collaboration**. Both terms play a central role in the conceptual framework proposed by this research (a detailed analysis can be found in Chapter 3).

Almost parallel to the work of Brown et al. on situated cognition was the idea that learning involves a deepening process of participation in **communities of practice**, developed by Lave and Wenger (1991). Their basic argument is that people are involved daily in diverse communities of practice (CoP), be they at home, school, work, or during urban and leisure activities, within which they engage in a process of collective learning in a shared domain of human endeavor. During participation in a CoP people pursue their common goals by sharing information and experiences, collaborating, and eventually developing personal and professional skills on the domain. Closely related to the cognitive apprenticeship model mentioned above is the **legitimate peripheral participation**, which characterizes the way new members of a CoP initially learn at the periphery before becoming full participants and plunging into the main processes of the particular community (Lave & Wenger, 1991). We would like to think of the audience of museum-based gaming activities as members of a CoP, and try to foster their learning by engaging them in the activities of this community, as much as possible.

**Distributed cognition** is another psychological theory drawing ideas from Vygotsky’s work, and emphasizing the social aspects of cognition (Hutchins, 1995). According to Hutchins, human cognition cannot be seen as an autonomous computational process confined to the individual; instead, it is a combination of distributed processes governing cognitive phenomena. In other words, human knowledge is distributed across the people, tools, and artifacts that surround us, and only through interaction with this information-rich environment we can make meaning and elicit learning. In conformity with the notion of situated learning, Hutchins states that “human cognition is always situated in a complex sociocultural world and cannot be unaffected by it” (p. xiii).

Vygotsky’s sociocultural psychology has also inspired the development of **activity theory**, a framework for describing human activities as complex, socially situated phenomena. Initially developed by the Soviet psychologist Alexei N. Leont’ev, activity theory has been exploited for guiding the design and evaluation of human-computer interaction systems (Nardi, 1996). The main idea of the framework is to help us understand how different components of an activity system (subject, object, artifacts, rules, community, and division of labor) work together in order to reach
2.1 Learning

an outcome. During our interaction with the system, our mental processes are “externalized” into tools which can thereafter be communicable to other participants of the community and, thus, facilitate social interaction. Since “meaningful learning is inextricably tied to activity,” more authentic activity is likely to induce more meaningful learning (Jonassen, 2000).

2.1.2 Dimensions of Educational Theory

Many theorists and educators have distinguished between learning as a product and learning as a process (John H. Falk & Dierking, 2000; Hein, 1994; M. K. Smith, 2003), or else what we learn and how we learn it. This dyadic approach to learning has formed an epistemology about the nature of knowledge and has also led research on educational theories over the years. Historically, educators were putting all their efforts on imparting knowledge (learning as a product) and especially assessing the degree that this knowledge was assimilated by students. During the last decades focus has shifted towards examining learning as a process; that is, investigating the best ways to facilitate learning, either within formal or informal educational settings.

The theory of knowledge which examines learning as a product is characterized by two opposing views. On one end are those who believe that knowledge exists independent of the learner and on the other end those who argue that knowledge is constructed in the mind of the learner. Similarly, the theory of learning encompasses two contrasting approaches: one is that learning constitutes an incremental assimilation of information, facts and experiences, while the other is that learning is a process of meaning construction (Hein, 1994). Behaviorists are, obviously, proponents of the former view by believing that learning is achieved through an additive sequence of stimuli-response instances, while constructivists are advocates of the latter view by postulating that learning occurs as a result of constructing cognitive structures from experiences within our environment.

The dichotomy of these two dimensions of educational theory, as proposed by Hein (1994), has produced the diagram of Figure 2-1, which presents the four possible combinations of the learning theory and the theory of knowledge. The main additions we have made to the diagram are the inclusion of experiential learning, as well as the social aspect of constructivism. The latter is because we consider social interaction to be of ultimate importance to informal learning settings, and especially public spaces like museums and science centers, or even location-based entertainment venues (LBEs), where a large number of people is gathered and engages in
interactive activities both with the computer-generated content, as well as with the other members of the audience. Learning in social contexts is a major factor in the current research, which assumes that the impact factor of learning collaboratively in LBEs is significant and largely unexplored.

**Figure 2-1.** Dimensions of educational theory [adapted from (Hein, 1994)]

The four quadrants of the above diagram represent four distinct approaches to learning, closely related to the theories we have reviewed in the previous section. The top left quadrant represents the position of traditional lecturing and text, where the teacher is the sole responsible for organizing the material (knowledge) in a logical manner, so that the students can understand and assimilate it more effectively. This view completely ignores the role of the learner in the learning process and assumes that imparting knowledge is purely a matter of structuring the material properly and using the appropriate teaching methods.

The position proposed by the bottom left quadrant is the same with the one adopted by behaviorists. According to this approach learning is acquired incrementally by careful guided instruction on behalf of the teacher, but knowledge is built up by the learner through a controlled
series of responses (answers) to stimuli (questions). Behaviorism, as a psychological learning theory, did not specify the type of knowledge acquired through these stimuli-response sequences.

Discovery learning, as initially proposed by Bruner, and experiential learning, as described by Dewey and Rogers, are the two learning theories subsumed within the top right quadrant. This position of education proposes that learning emerges through the engagement with authentic experiences, acting on situations rather than watching or reading about them, and participating in activities which require critical thinking and hands-on exploration. At this point, we overemphasize that through such hands-on (gaming) experiences, which can take place either individually or collaboratively, students usually construct, and not simply comprehend, the concepts and ideas involved in the activities. Hence, the arrow in the above diagram indicates that—in some cases, like the one proposed by this research and analyzed in the next sections—there is an added benefit of combining discovery/experiential learning with social constructivism. In these cases, knowledge, which might be objective and largely independent of the learner, is constructed collaboratively by the learners through active participation in meaningful, socially rich experiences, such as the ones offered in museum spaces.

The last position, presented at the bottom right quadrant, coincides with the most recent, and maybe the most fruitful, educational theories: Piaget’s constructivism, Papert’s version of constructionism, and the sociocultural constructivism of Vygotsky. According to the latter approach, learning entails a series of culturally dependent personal and social interactions with our environment, through which we adapt our existing cognitive structures, and as a consequence knowledge is created. This type of knowledge, constructivists believe, is significant only in the mind of the knower and has no value secluded from the learner. This radical view of constructivism (von Glasersfeld, 1990) does not constitute part of the current research, which focuses more on the assimilation of factual and procedural knowledge through games and social interaction, than of abstract concepts which is the core application field of constructivist instructional approaches in—mainly science—education.

2.1.3 Learning in Informal Settings

The dimensions of educational theory included in the right half of the aforementioned diagram have found their way, over the last decade, in public places like museums, science centers, and LBEs in general. These informal learning settings, as they are being called, have provided fertile
ground for the cultivation and evaluation of discovery, experiential, constructivist, and social constructivist learning practices. This trend for learning that occurs outside of the classroom will play such a critical role in tomorrow’s education, bridging the gap between learning in school and learning in daily life, that “the school of the future may look more like a theme park or an interactive museum than [a] traditional classroom” (Crocker, 2003).

However, we still have a long way to go, since the overwhelming majority of studies and research work about learning has been carried out so far within classrooms or research laboratories, which constitute inappropriate settings for evaluating free-choice learning in out-of-school contexts (John H. Falk & Dierking, 1992). The term free-choice learning was more preferred by Falk and Dierking than the more frequently used informal, in that it encompasses “the underlying motivational and structural nature of the learning that occurs in and from such settings” (John H. Falk & Dierking, 2000, p. xii). According to their view, the type of learning occurring in museums, and other similar settings of free-choice learning, is as powerful and as long lasting as the one happening through formal education. As a reinforcement of this view, we refer to the term task-conscious or acquisition learning that Alan Rogers (2003) ascribed to the type of learning taking place unconsciously, while we are engaged in completing various tasks in everyday life (e.g., fixing a car or visiting a museum). On the other hand, learning-conscious or formalized learning is the educative type of learning taking place in the classroom or other places where learning itself is the task.

A rather important review of the lifelong learning that takes place in museums, galleries and science centers has been carried out by the Futurelab organization (Hawkey, 2004). In their technical report they have examined the effective learning attributes that arise from the synergy of free-choice, explorative learning and digital technologies in museums and other institutions for the general public. Indeed, the learning potential that such spaces bear, especially if augmented with the latest advancements of today’s information technology (e.g. interactive multimedia, 3D graphics, Virtual Reality, mobile devices, etc.), we consider being immense and pivotal to this work. Hence, Resnick (2002) has argued that “in the digital age, learning can and must become a daylong and lifelong experience”, where “education initiatives should aim to improve learning opportunities not only in schools, but also in homes, community centers, museums, and workplaces.” (p. 32).
2.1 Learning

Such a radical stance concurs with Howard Gardner’s view of exploiting the learning that takes place outside school, as a means of fostering the multiple intelligences owned by individual students. By employing a multitude of ways for the presentation of material, informal learning practices allow for students to opt for the best methods of acquiring their own understandings (Gardner, 2004). Furthermore, Gardner emphasized how current sciences of learning have mainly addressed the psychological, neurological, and computational side of humans, downgrading the significance of our historical, social, and cultural nature. Indeed, the majority of learning studies so far investigated learning in scientific subject matters, and undervalued the exploration of effective ways for disseminating knowledge of literary, cultural, and historical significance. Thus, it is the intention of this study to contribute towards filling this gap by employing a subject of cultural heritage, but also assessing the impact of sociocultural idiosyncrasies on learning and engagement in informal education settings.

Overall, there are three factors that we believe play a significant role in the informal learning taking place in museum settings, especially when utilizing interactive properties such as the ones employed during our research. First is the prior knowledge employed by the learners in order to make meaning of the information provided; second is the importance of context in this meaning making process; and third is the impact of culture on the learning styles and behaviors of the students. We will elaborate further on these three factors, which we consider to greatly affect the type of learning happening with groups interacting with technology in museums.

2.1.3.1 Learning from prior knowledge

In order to make meaning out of new experiences, we must understand how prior knowledge affects learning. Initially, it should be clear that prior knowledge defies the conventional transmission-assimilation view of learning; instead it coincides with the stance that learning is a result of conceptual change. Only when we change our inner mental models of a situation, by diverging from the ordinary ways of observing, perceiving, reasoning, and justifying, we are able to comprehend and adopt the concepts involved (Strike & Posner, 1985). This means that prior knowledge raises a barrier to learning new concepts and facts when they contradict with what we already know. This barrier, which is also known as the “paradox of continuity,” should be dealt with care by educators, by assisting learners to refine and reconstruct their prior knowledge in accord with new information and experiences (Roschelle, 1997).
The theories of learning we have reviewed in section 2.1.1 have attempted, in one way or another, to overcome the paradox of continuity. Most well-suited is Piaget’s theory of child development, according to which learning (conceptual change) is the continuous process of adapting to the environment, by means of assimilation (using prior knowledge to deal with situations) and accommodation (transforming prior knowledge to interpret events). The tension emerging from the conflict between assimilation and accommodation when performing a task, could eventually lead to conceptual change, by engaging children in interactive experiences and providing the tools to resolve the conflict and make sense of the problematic task on their own.

Dewey’s work on experiential learning has also made allowances for coping with the paradox of continuity. By considering children’s knowledge as fluid, flexible, and generative, Dewey (1938) urged educators to provide ways of sketching, exploring, and experimenting with the ideas contained within the more firm, definite, and structured content of organized taught material. Dealing with problematic experiences containing such material, demands a transformation of prior knowledge, which results in restructuring thought, perception, and actions into a coherent whole. The repetition of such transformations over time, with appropriate guidance, results in forming this integrated whole into concrete new knowledge about the material.

According to Vygotsky’s sociocultural theory, advanced concepts are initially revealed through social interaction and then become accessible to the individual. The ZDP plays a very important role to this transformative process of prior knowledge to conceptual change. The child contributes during social interaction by employing his/her prior knowledge, and it is with the guidance from or collaboration with others that this knowledge is externalized, communicated, negotiated, and eventually transformed into new knowledge. Also, through modeling and scaffolding by experienced guides, social interaction between participants and the process of transformation are facilitated. For this reason, we also plan to assess the impact of facilitation during the discovery learning process employed by the developed system (more in Chapter 4).

However, achieving conceptual change in practice in informal education settings is no trivial task. The process demands great effort, persistence and time, which are usually not available in a single or short series of visits in public spaces like museums or science centers (Roschelle, 1997). Nonetheless, learners (or educators, in case of school visits) usually self-select which institutions to visit and what programs to attend, according to prior knowledge, interests, and
beliefs (John H. Falk & Dierking, 2000). This fact commissions the museum with the responsibility to provide high quality experiences that engage prior knowledge, and overcome achievable (intellectual) challenges by employing the appropriate physical, intellectual, and social resources (Csikszentmihalyi, 1990). We assume that collaboration with games and virtual environments have the power to do so, thus we review them in the following sections.

Having emphasized the importance of prior knowledge in reinforcing understanding and facilitating learning within museums, Falk and Dierking analyzed the way “learning occurs best when accompanied by supportive contexts” (p. 30). Knowledge acquired within the museum will eventually obtain meaning and result in conceptual change, when put in context and applied in subsequent experiences. Nonetheless, the museum space provides ample opportunities for exposing visitors to highly contextual information during the visit that can aid prior knowledge, also instigating their curiosity and interest for further exploration.

2.1.3.2 Contextual learning

“Learning is contextual: we do not learn isolated facts and theories in some abstract ethereal land of the mind separate from the rest of our lives: we learn in relationship to what else we know, what we believe, our prejudices and our fears. On reflection, it becomes clear that this point is actually a corollary of the idea that learning is active and social. We cannot divorce our learning from our lives.” These words by George Hein (1996), an expert in museum education, reveal the decisive role of context in eliciting learning within public institutes.

The notion of learning within context builds primarily upon the theory of situated cognition, according to which “knowledge is situated, being in part a product of the activity, context, and culture in which it is developed and used” (J. S. Brown et al., 1989). This process, the authors argue, resembles the way we make meaning out of indexical words (e.g., now, then, him) in a sentence, by interpreting them in the context of their use. Consider knowledge as a set of tools serving a particular task; learning how to use these tools requires you knowing the way they work, being involved in authentic situations that call for their use, and adopting a world view of the culture that uses them. This explains why curriculum material fails to provide the desired learning outcomes: activities cease to be authentic and lose their context when transferred into classrooms and transmuted to tasks of the school culture. Institutions of informal learning have the supreme
advantage of engaging their audiences, either physically or virtually, in authentic activities which preserve their contextual attributes.

We would like to think of the audiences engaged in such activities as the communities of practice (CoP) defined by Lave and Wenger (1991). Members of these communities are organized around a particular area of knowledge and share mutual interests, repertoire of ideas and commitments, in order to achieve a common goal. Learning taking place in CoP is not attributed to cognitive processes and conceptual structures, but rather to engagement in contextually significant activities through social interactions, communication of intentions, and collaborative practices. The role of cognitive apprenticeship (J. S. Brown et al., 1989) or legitimate peripheral participation (Lave & Wenger, 1991) in informal education settings is rather important, in that it allows participants to initially learn the necessary knowledge and skills, before applying them in authentic problem-solving situations, while also switching from spectators to participants at will.

This type of contextual learning in museums is highly acclaimed by Falk & Dierking (2000), who have proposed the Contextual Model of Learning in order to interpret the nonlinear, personally motivated, free-choice learning taking place in such public spaces. Learning, according to their model, is conceptualized as the integration and interaction of three overlapping contexts: the personal, the sociocultural, and the physical. These contexts encompass eight key factors that affect learning in museums. For the current research, which is addressed to the technologically-enhanced museum or science center, we have concentrated on five of them from the first two contexts:

- **Motivation and expectations**: learning is facilitated when expectations about the visit are fulfilled and when intrinsically motivated individuals are attracted and reinforced.

- **Prior knowledge, interests, and beliefs**: meaning making of the experience is framed within, and constrained by, prior knowledge, interests and beliefs.

- **Choice and control**: learning is ultimately achieved when individuals can exert choice over the type and pace of the content and feel that they are in control of their own learning.
• **Within-group sociocultural mediation:** collaborative learning is fostered through the social interactions of group members, by virtue of deciphering information, reinforcing shared beliefs, and making meaning.

• **Facilitated mediation by others:** learning can be enhanced (or hindered) through the contribution of expert guides (e.g. museum educators, explainers, performers, etc.) or more skillful co-participants.

Although the facilitation of learning during museum visits *per se* is not our primary concern, we consider this factor as potentially beneficial to enhancing the learning and engagement outcomes of a museum visit and will evaluate it in one of our studies.

### 2.1.3.3 Culture and learning

Most theories of learning and knowledge, as reviewed under Section 2.1, do not usually account for the learners’ culture as a determining factor affecting how they learn. This disparity between learning and sociocultural sciences arises from the fact that the former is focused on commonalities in learners’ behaviors, in order to build effective instructional tools, while the latter focuses on the different ways that people approach, interpret, and troubleshoot problems (Pinkard, 2004). An exception is Vygotsky’s sociocultural theory of learning, according to which “cognitive development was treated as a process of acquiring culture,” where higher psychological functions were first shaped through social interactions before being internalized by the individual child (Cole, 1985). However, most of the work based on Vygotsky’s theory does not try to assess the differences of how children learn between cultures, but rather how cognitive development is transformed through social interactions.

The majority of the work assessing the impact of culture on learning has been done in the context of online, mostly asynchronous, collaborative environments. Vatrapu performed an experimental study to investigate how varying social affordances (cognitive processes) and technological intersubjectivity (social behavior) might affect collaboration in online learning environments, across and between cultures (Vatrapu, 2008). Similarly, Kim and Bong reported cross-cultural differences in online collaborative behaviors among Finnish, American, and Korean undergraduate students (Kim & Bonk, 2006). In most cases, research is focused on the identification of design specifications for multi/cross-cultural online collaborative tools (Fussell
& Zhang, 2007), and does not include differences across cultures while engaged in the rich social interaction experiences afforded by collocated collaborative play.

Nonetheless, most of the evidence supports the importance of learning styles and perceptual development, as they are affected by the learners’ culture. Indeed, children learn in different ways depending on the learning styles they have adopted at an early stage through family, and according to the situation, task, or materials being used in the educational practice (Cox & Ramírez, 1981). More specifically, it has been noted that concept development can occur either through working in groups observing and modeling what other people do (field-sensitive learning) or through experimentation and trial and error (field-independent learning). In the latter case, children might not feel as being part of a group nearly as much as children coming from field-dependent families, and tend to build knowledge in an individual manner.

This fact has also implications on how children develop self-confidence and self-esteem, especially when operating inside a social context, since learning is largely a process of affirming self (John H. Falk & Dierking, 2000; Triandis, 1989). Learners’ interests, attitudes, and choices about learning are greatly affected by dimensions of self-concept like self-esteem, attribution, and fate control. A major determinant of social behavior is the kind of self that operates in the particular culture (Triandis, 1989). Different cultures nurture different values and belief systems, shaping individual self-actualization and socialization patterns (e.g., individualism vs collectivism), which, we assume, can affect collaborative game play attitudes, and eventually engagement and learning outcomes. Hofstede’s cultural dimensions theory provides a useful framework for assessing the behavior of people based on their culturally imposed societal values (Hofstede, Hofstede, & Minkov, 2010).

Furthermore, students interpret situations in a learning context differently depending on their perceptual development, which is greatly affected by their culturally-dependent meaning making process (Shade, 1989). The more loose and unstructured the learning context, the greater the need to provide cognitive aids that will facilitate meaning making for diverse learning styles and levels of perceptual and cognitive development. Scaffolding is one way to accommodate the cultural diversity of museum visitors, but has rarely been assessed in informal learning. In one study, middle school students in groups of three were used in an actual museum space to learn about electrical conductivity, using a physical exhibit with digital augmentation or knowledge-
building scaffolds (Yoon, Elinich, Wang, VanSchooneveld, & Anderson, 2013). Assessing the impact of scaffolds on informal behaviors (comprised of experimentation and student-generated questions) as a measure of interest and engagement, researchers found a significant increase of informal behaviors as collaboration increased, but such behaviors decreased with the increase of scaffolds. However, deeper cognitive gains were only exhibited when scaffolding was present.

Facilitation is yet another way to counteract the adverse effects that might arise from the dissociation between the learners’ (culturally dependent) cognitive ability and learning style, and the medium’s dissemination format. Although games have been widely used for educational purposes over the years with minimal instructional assistance (more in Section 2.4.4), accumulating evidence suggests that unguided instruction during discovery learning often proves to be less effective as compared to guided instruction (Mayer, 2004). Moreover, purely constructivist and discovery learning environments, as the ones usually adopted by museums, have been heavily criticized as ineffective by scholars who postulate that minimal guidance during an instructional activity is not enough to facilitate the cognitive processing necessary for learning (Kirschner, Sweller, & Clark, 2006). However, these voices come largely from people who advocate the cognitive information processing view of learning (deriving from cognitivism).

In any case, museums should strive to satisfy “visitors' cultural contexts for learning” by means of recognizing and respecting the diverse values and norms of the culture, but also include a variety of educational approaches adopted from other cultures in museum programs and activities to enhance the learning experience (Chang, 2006). Computer games, as a universally popular technology to the youngsters of the western world, bear the promise of overcoming the burden of facilitation demands by developing adaptable instructional practices according to the learners’ culture. We speculate, and will investigate through one of our studies, that employing collaborative gaming for educational purposes will facilitate learning for a culturally diverse audience with minimal, if any, modifications in the system design.

2.1.4 Learning with Technology

The evolution of all the educational theories described above, from behaviorist to cognitivist to social constructivist has guided the development of technology-enhanced learning (TEL) applications. The term TEL encompasses all the learning activities that employ technological support in order to facilitate their pedagogical purposes. Below follows a brief reference of how
such applications have progressed over the years and the way they have been exploited, within both formal and informal education settings.

Behaviorism, as the dominant theory during the 1960s and 1970s, imposed the development of computer-aided instructional design, which entails identifying the learners’ current knowledge and needs, defining the end goal of instruction, and providing the necessary tools for assisting the transition towards this goal. Initially, there were programmed instruction systems, based on Skinner’s theory, which presented material in a linear manner and tried to elicit learning through repetitive sequences of question, response, validation, and feedback. Such systems have evolved to branched multiple-choice instruction, where different paths of instruction were followed depending on the chosen answer. Eventually, Gagne’s conditions of learning led to the development of drill-and-practice applications, which aimed at increasing student acquisition of basic skills (e.g., addition, spelling, and vocabulary) through repetition. Instructional design and drill-and-practice applications were initially used for training (especially military) and then moved into classrooms. Simple as they may have been, these early implementations of educational software employed—even at its basic form—one of the fundamental characteristics of technology: *interactivity* (a detailed analysis of its implications for learning can be found under Section 2.2).

During the 1970s, the increased research on the cognitive aspects of learning, led to the development of microworlds. A microworld is a tiny “world” inside which a student can explore alternatives, test hypotheses, and discover facts that are true about that world\(^7\). Maybe the most famous microworld is the Logo “turtle” developed by Seymour Papert and Marvin Minsky of MIT as a test bed for Papert’s constructionist model of learning. Logo is a programming language, mainly for children, which allows students to draw geometrical shapes either on screen (turtle avatar) or on the floor (robot turtle), by writing simple commands. Papert considered the turtle as an “object to think with,” as a cognitive tool that enabled children to perform the constructive thinking and conceptual exploration that would not be possible without the help of the technology (Papert, 1980a). Logo was initially used in classrooms for teaching geometry and mathematics, but lately has inspired work on more advanced educational technologies, such as simulations, smart objects, video games, and more\(^8\).

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\(^7\) Definition of microworld by Larry Latour, retrieved on October 2014 from: http://www.umcs.maine.edu/~larry/microworlds/microworld.html

\(^8\) Mainly developed at MIT’s Lifelong Kindergarten group, dedicated to the research of innovative technologies that foster creative activity. Found at: http://llk.media.mit.edu/ [last accessed: October 2014]
The advent of personal computing in the 1980s, gave way to the development of software accessible to the broad public, either for work or leisure. Amongst such applications, which allowed specifically the evaluation of constructivist, exploratory, and experiential learning theories, were simulations and games. Simulations resembled microworlds, with the only difference that they were clearly imitating a real-life or hypothetical situation and not an imaginary world. They were broadly used for military or professional training (e.g., practice of fighter pilots), but later moved to education as a means of allowing students to model natural systems in many disciplines like physics, chemistry, biology, engineering, etc. Computer games with complex scenarios and impressive graphics started to emerge at the same time, taking advantage of the vertiginous pace that personal computers (running the freshly-released Macintosh and Windows operating systems) and game consoles (e.g., Atari, Amstrad, Amiga, etc.) were penetrating homes. Microworlds, simulations, and games (reviewed further in Section 2.4) have been considered appropriate means of learning facilitation, by dint of exercising critical thinking and problem-solving skills (Rieber, 1996).

The exorbitant growth of the Internet during the 1990s, and the introduction of the user-friendly World Wide Web protocol (www) at the outset of the decade, allowed easy access to any form of information anywhere in the world. The proliferation of Internet technology boosted the development of applications that allowed collaboration of geographically distributed users. Computer networks allowed students on remote or collocated workstations to learn together effectively, under the supervision of an instructor, thus giving rise to the field of Computer-Supported Collaborative Learning (CSCL). Work on the field of CSCL has been inspired by the sociocultural theories of Vygotsky, situated cognition, and the communities of practice, reviewed earlier. So significant the added value of CSCL was considered to education, that distance learning became a formal pedagogical practice, leading to the materialization of online courses and virtual classrooms, and even to the establishment of institutions providing courses merely through the Internet (e.g., Open Universities and, more recently, Massively Online Open Courses). Although the term CSCL usually entails collaborative learning through distance, there have been recently quite a few attempts to facilitate collocated collaboration, which is indirectly related to our research; therefore, we will elaborate further on it in Section 2.3.

9 Collaboration in collocated environments involves usually interaction and cooperative work of few individuals, using either desktop computers or more often non-desktop devices (e.g., handheld devices, wall-sized or tabletop displays), but rarely the audience collaboration paradigm additionally investigated in this research.
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The rapid evolution of computational power that occurred during the last years of the millennium pushed forward the production of high quality 3D graphics, and eventually the development of computer hardware that could handle such data load in real-time. This meant that Virtual Reality (VR) applications were, more than ever, accessible to a wider range of researchers, educational institutions, and production companies. VR, as the emerging technology of the time, enabled representation and manipulation of various forms, objects, processes, and occurrences of the past in three dimensions, thus permitting experimentation with abstract scientific concepts and exploration of important historical periods and events. Abundant research practices have attempted, over the past two decades, to assess the learning efficacy of such VR implementations, especially employing the constructivist and exploratory dimensions of education. Such research is closely related to our work; hence, further investigation on VR applications, with an emphasis on learning, is presented in Section 2.5.1.

The advent of the 21st century has changed the conventional way we think of the computer to a “disappearing” computer. Ubiquitous computing, as it is widely known (Weiser, 1991), is a new paradigm of human-computer interaction where people interact with the technology and with each other in natural ways, without being aware of the computer’s mediation. Striving for this trend to “physicality,” as Donald Norman named it (Norman, 2007), has led research on such diverse fields as natural user interfaces, ambient intelligence, wearable computers, smart devices, mobile phones, pervasive games, mixed and augmented reality, and immersive displays. All of these technologies play an important role in shaping the future of technology-enhanced learning, by virtue of transforming the way we currently interact and learn with computers to a seamless intercommunication of sensor-driven devices, engaging most senses, inducing emotions, and unconsciously eliciting learning. Although it lies out of the scope of the current research to examine learning with such advanced technologies, we will briefly review the potential pedagogical impact of psychological immersion (or presence), as one of the fundamental properties of virtual environments (Section 2.5.1.2).

2.1.5 Section Summary

We have initially reviewed the most influential theories that have formed educational practices during the last fifty years. From the behaviorist approach to learning, applied mainly in the formal instruction methods of schools, we have reached the constructivist and social constructivist views,
which have been exploited in museums and other institutions of informal education. We have then explicated the way that learning as a product (what we learn, i.e., knowledge) and learning as a process (how we learn it) have formed the dimensions of educational theory, which encompass most of these learning theories. We have suggested that discovery and experiential learning might induce knowledge construction on behalf of the learner, and are not necessarily methods of ready-made knowledge transmission. Such exploratory learning practices in conjunction with social constructivist pedagogical methods, we consider to be fundamental for the type of game-based learning that we investigate in this research for informal education settings.

We have further examined the type of learning that occurs within such free-choice learning settings as museums, science centers, and LBEs\textsuperscript{10} in general. We have elaborated on the way current trends in technology are shifting learning from the typical classroom to virtual classrooms emerging in these settings, mainly by way of exploiting their sociocultural properties. Learning in such spaces is accomplished effectively if it is contextual, if it takes advantage of visitors’ prior knowledge, and if it is appropriate for the visitors’ cultural background. We have reviewed how these three factors are connected with the theories of situated cognition and the communities of practice, emphasizing on the properties of Falk and Dierking’s Contextual Model of Learning which we consider are closely related to our research. Finally, we have made a brief historical flashback on how technology has aided the application of the theories of learning within diverse educational settings. This review enabled us to situate the integrated components of our research within a time framework and provide a conduit for the following sections.

2.2 Interactivity

Interaction is a continuing increase in participation. It’s a bidirectional communication conduit. It’s a response to a response. It’s “full-duplex”. Interaction is a relationship. It’s good sex. It’s bad conversation. It’s indeterminate behavior, and it’s redundant result. It’s many things, none of which can be done alone. Interaction is a process that dictates communication. It can also be a communication that dictates process. It provides options, necessitates a change in pace and changes you as you change it.

-Mark Stephen Meadows\textsuperscript{11}

\textsuperscript{10} We have used LBEs here to also include a combination of education and entertainment, such as the one occurring in museums and science centers, and not only entertainment-based venues such as theme parks.

Interactivity has appeared with many faces in many research disciplines since its appearance, mainly, in the late 1980s. Scholars from media, communication, sociology, education, and more recently information and computer sciences have attempted to define interactivity by virtue of identifying its components and enabling their effective exploitation. The purpose of such endeavors has always been to provide a deep understanding of the term and its implications, thus allowing researchers and professionals in these fields to employ interactivity for achieving their goals more effectively (i.e. communicating a message, enhancing user-friendliness of an interface, or facilitating learning). No matter which field of expertise lies behind each definition of interactivity, we consider the one quoted at the beginning of this section to be general enough to encompass all of its basic attributes and characteristics.

This section commences with a literature review on the various definitions given to interactivity from scholars of diverse disciplines, followed by an inspection of the levels or dimensions that have been prescribed as determinants of the quality and degree of interactivity. Then, we continue with a critical survey of the ways that interactivity has been exploited and evaluated by researchers as a means of facilitating learning, identifying differences and similarities with this study. We conclude with a concise reference of the history and common practices of audience interactivity.

### 2.2.1 Definitions of Interactivity

One of the first and most oft-quoted definitions of interactivity comes from Sheizaf Rafaeli and the field of mass communication, although—as he declares—its application can be broader (Rafaeli, 1988). According to his working definition “interactivity is an expression of the extent that in a given series of communication exchanges, any third (or later) transmission (or message) is related to the degree to which previous exchanges referred to even earlier transmissions” (p. 111). These communication exchanges are deliberate and in order to achieve full interaction the roles of communication transmitter and receiver must be interchangeable. Refaeli also argued that because interactivity is easily recognizable in new media it should not remain an underdefined concept; rather its theoretical power should be revealed and rigorously examined.

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12 Interactivity is usually used to express a property of the medium, while interaction refers to the communication or participation process of using interactivity.
Following Rafaeli’s prompt, many researchers have since provided operational definitions of interactivity focusing on the idiosyncrasies of diverse disciplines, without however disambiguating the concept considerably. This is accounted chiefly on the fact that there has been no consensus on how to interpret interactivity, which has mainly been examined as a simulation of face-to-face communication (Heeter, 1989), lacking the characteristics of technologically-mediated environments that most interactive experiences are associated with (Kiousis, 2002). Another reason for the complexity of its definition is that while some scholars have regarded interactivity as a feature of the medium dependent on technology (Heeter, 1989; Jensen, 1998; Sims, 1997; Steuer, 1992), some others have considered it to depend on user perception (McMillan, 2000; Murray, 1997; Wu, 1999). Nonetheless, there have been definitions that make allowances for both perspectives (Downes & McMillan, 2000; Ha & James, 1998), and one additionally takes into consideration interactivity as a characteristic of the communication context within which messages are exchanged (Kiousis, 2002).

As stated before interactivity is a concept that spreads among many disciplines; principally in sociology, where it is considered “a reciprocal relationship between two or more people”, in communication, where it refers to “the relationship between the text and the reader, but also reciprocal human actions and communication associated with the use of media”, and in informatics, where it refers to “the relationship between people and machines” (Jensen, 1998, p. 190). Jensen, after scrutinizing definitions of interactivity as prototype, criteria or continuum, concluded that the latter appears more appropriate and flexible in relation to the diverse technologies tampering with the concept. Thus, he came up with a view of interactivity as “a measure of a media’s potential ability to let the user exert an influence on the content and/or form of the mediated communication” (p. 201).

Similarly, Steuer (1992) in an attempt to define the dimensions that determine telepresence in virtual reality environments defined interactivity as “the extent to which users can participate in modifying the form and content of a mediated environment in real time” (p. 84). Such technology-driven definitions are clearly inclined towards computer-mediated communication and human-computer interaction (HCI), where the notion of control is of vital importance. These approaches coincide with one of the first definitions of interaction related to the field of HCI, provided during an international workshop titled “The Methodology of Interaction” that took place in France in
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1980, according to which “interaction is a style of control and interactive systems that exhibit that style” (Guedj, Hagen, Hopgood, Tucker, & Duce, 1980, p. 69; cited in Jensen, 1998, p. 190).

One type of such interactive systems, which proliferated during the early 1990s and served as a test bed for the first technology-driven definitions of interactivity, are Web sites. It was the World Wide Web that led scholars to depart from the traditional communication models of interactivity and reconceptualize the term, in order to cope with the increased interactivity needs emerging from the evolution of new technologies (Heeter, 1989). One attempt to conceptualize interactivity within the context of business web sites pushed forward the view that “interactivity should be defined in terms of the extent to which the communicator and the audience respond to, or are willing to facilitate, each other’s communication needs” (Ha & James, 1998, p. 461). This approach abolishes the unrealistic notion of mutual interest in two-way communication and makes room for different levels of control from both interacting sides (in this case the web site visitor and the owner company).

The use of web sites has also guided research on the view that interactivity resides in the perception of those participating in communication or else “perceived interactivity”, as opposed to “functional interactivity” which considers interactivity a function of the medium. A strong advocate of this approach, Sally McMillan, assessed the four types of interactivity (or “models of cyber-interactivity”) that she had devised on four Web sites about race walking, and found positive correlation between perceived interactivity and attitude toward the Web site as well as perceived interactivity and involvement in the subject matter (McMillan, 2000). Further evidence of such belief had been provided by Wu (1999), who contended that perceptions of interactivity have a significant impact on users’ attitude toward Web sites; a finding he believes should guide the design and development of Web marketing and advertising. Contrary to such finding, although grounded by the same view of perceived interactivity, is the “perceived purpose of communication” defined by Downes and McMillan (2000), who suggested that mediated communication based on information exchange is more interactive than communication perceived to have persuasive purposes.

Spiro Kiousis tried to embed all the above conceptualizations in an integrated definition, which takes into account all three views of interactivity as formerly defined by others; namely the technology, the communication setting, and the perceiver (Kiousis, 2002). According to his hybrid
definition “interactivity can be defined as the degree to which a communication technology can create a mediated environment in which participants can communicate (one-to-one, one-to-many, and many-to-many), both synchronously and asynchronously, and participate in reciprocal message exchanges (third-order dependency). With regard to human users, it additionally refers to their ability to perceive the experience as a simulation of interpersonal communication and increase their awareness of telepresence” (p. 372). Kiousis’ explication considers interactivity as both a media and psychological variable.

Brenda Laurel in her seminal book *Computers as Theater* also resorted to human agency as a means of simplifying the troublesome concept of interactivity. While avoiding to provide a concise definition of the term, she preferred to propose a “more rudimentary measure of interactivity: You either feel yourself participating in the ongoing action of the representation or you don’t” (Laurel, 1993, pp. 20–1). Such a proposition has ramifications on other issues pertinent to HCI, especially in VR environments, like sensory immersion and the feeling of presence (reviewed briefly in Section 2.5.1). Moreover, Murray emphasized the importance of increasing user awareness of mediated environments over physical ones in order to amplify the sense of interacting with the objects and characters inhabiting those environments (Murray, 1997); a notion that too has its roots in VR technology.

The design of effective Virtual Environments (VEs) hinges greatly upon their interactive properties. Within such designed experiences, as the one proposed by this work, interaction can be defined as “an episode or series of episodes of physical actions and reactions of an embodied human with the world, including the environment and objects and beings in the world. These actions and reactions are actual interactions, a subset of the range of potential interactions of the human and the world at that time and place” (Heeter, 2000, p. 7). Heeter goes on to praise the importance of creating personas (or avatars) in designed experiences, taking advantage of the human capacity to respond to technology as if it is human, and wonders what will be the consequences of having more real actors participating in the mediated experience. Eventually, she proposes a participant-centered perspective on interactivity (analogous to the aforementioned “perceived interactivity”), according to which interaction is “to experience actions the participant is capable of observing through one or more senses over whatever channels exist to connect the participant to the experience” (p. 11).
Providing memorable experiences in informal education settings (e.g. museums, galleries, science and cultural centers, etc.) and LBEs is paramount for the ultimate impression of the visitor. Within such contexts the term interactive has been used by Adams and Moussouri (2002) to “refer to this family of experiences that actively involve the visitor physically, intellectually, emotionally, and/or socially.” This is also the intention of our study; more specifically, the intellectual, emotional, and utmost social involvement of our audience in a cultural VR experience. By adopting Rokeby’s approach to interactivity that “the experience of culture can be something you do rather than something you are given” (Rokeby, 1998, p. 27), we anticipate that involving an audience of children in meaningful interaction with educational material will elevate their overall—and consequently learning—experience. Closely related to Rokeby’s view of using interface as content comes the strategy in VR application design proposed by Parés and Parés (2001), according to which design is driven by closely studying the proposed interaction, with the interface metaphor and the application context being derivatives of this process. This interaction-driven strategy will guide the design of the VR application with group collaboration developed in the context of this dissertation work.

2.2.2 Dimensions of Interactivity

Most of the scholars who provided a definition of interactivity have also identified various attributes which concentrate on different perspectives of the concept. These attributes, which are also called dimensions, types, degrees, levels of interactivity or modes of interaction, attempt to demarcate the boundaries between the various kinds of interactivity as expressed within the diverse disciplines that employ them.

As mentioned before, Rafaeli (1988) was one of the first to define interactivity in the context of new media and communication. Along with his third-order dependency definition and having clearly stated that “interactivity is quintessentially a communication concept” (p. 113), he provided three pertinent levels: two-way or non-interactive communication (where messages flow bilaterally), reactive or quasi-interactive communication (where additionally later messages refer to earlier ones), and fully interactive or responsive communication (where the content, nature, form or mere presence of an earlier reference is incorporated in new ones). The model proposed by Rafaeli distinguishes between interactivity and feedback, in that “interactivity is feedback that
relates both to previous messages and to the way previous messages related to those preceding them” (p. 120).

Another taxonomy stemming from communication studies is the one provided by Carrie Heeter (1989), who proposed an understanding of interactivity as a multidimensional construct. The six dimensions of interactivity she defined are: provision of user choice (also called “selectivity”), effort users must exert to access information, medium responsiveness to the user, monitoring system use, ease of adding information accessible to an audience (many-to-many communication), and facilitation of interpersonal (one-to-one) communication. Moreover, Jens Jensen (1998) after analyzing the multiple dimensions of the concept provided by others, concluded on four sub-concepts defining interactivity in media and communication fields: transmissional (choose information in one-way media systems), consultational (choose by request from pre-produced information in two-way media systems), conversational (produce and input information in two-way media systems), and registrational (register information from and adapt/respond to the user). Jensen concludes with a 3D representation of the dimensions of interactivity which he calls the “Cube of Interactivity” (pp. 201-2), encompassing most of the technology-mediated communication media of his time.

The concept of interactivity has also been examined by many scholars in the context of instructional design. Jonassen (1988) identified five levels of interactivity focusing on user involvement with the application domain and subsequently on effective learning. The five levels, which are modality of learner’s response, nature of the task, level of processing, type of program, and level of intelligence in design, were suggested to affect the efficacy of learning. Schweir and Misanchuk (1993) introduced a rigorous taxonomy of interactivity in multimedia instruction based on three dimensions: levels (reactive, proactive, mutual), functions (confirmation, pacing, inquiry, navigation, elaboration), and transactions (keyboard, mouse, touch screen, voice). The higher level indicates more effective instruction, which in the case of this research includes mutual “artificial or virtual reality design, where the learner becomes a fully franchised citizen in the instructional environment” (p. 12). Also, Sims (1997) proposed three dimensions for interpreting interactive instruction: engagement (refers to interactivity which is either navigational or instructional), control (refers to the extent that the program or the learner are making the decisions), and interaction (provides an indication of the expected type of interaction). Sims concludes by contending that we should strive for the implementation of interactions at the learner-controlled,
instructional-engagement level (or the mutual-elaboration level according to Schwier and Misanchuk), in order to “motivate and engage the learner” and assure the “success of functional and effective interactive instructional applications” (p. 169).

In an attempt to operationalize the concept of interactivity in computer-mediated environments, Downes and McMillan (2000) interviewed ten people from the field of interactive communication and came up with six varying levels of interactivity. They have separated them to message-based dimensions: direction of communication (one-way or two-way), time flexibility (meeting the time demands of participants), sense of place (sense of being in the environment), and participant-based dimensions: level of control (being in command of the environment), responsiveness (perceiving the system as responsive), and perceived purpose of communication (informative or persuasive). Like most of the other models of interaction the authors recognized that there can be differing values across the continuum of each dimension, affecting the degree of interactivity perceived by the user. Thus, in a VE like the one used in this research values are believed to be on the high-end of the continuum; two-way communication between audience members and the system, flexible timing of messages (on user demand), immersion in the environment (feeling of presence), high level of control over the experience, responsive feedback, and focus on (cultural) information exchange.

Sally McMillan (2002) has also explored interactivity in new media environments from the perspective of the user, segregating between three distinct types: user-to-user (interpersonal interaction), user-to-documents (interaction between the user and the content), and user-to-system (human-computer interaction). For each of the three types, she defined four models of interactivity that attempt to categorize most instances of interaction deriving from the juxtaposition of the level (high/low) or the locus (human/computer) of control, as the central factor, with the direction of communication (one-way/two-way), the nature of the audience (passive/active), and the interface (apparent/transparent), for the three different types respectively. Similarly, Sutton (2001) expands on the previously defined four basic types of interaction in distance education; namely learner-learner, learner-content, learner-interface (germane to McMillan’s tripartite model), and learner-instructor (distinct for instructional education), also adding vicarious interaction which encompasses all four types and allows a student to learn by observing others’ interactions with content, instructor, other learners, and interface. The system used in this research will employ all three of McMillan’s types of interaction. We also consider vicarious interaction to play a crucial
role in assisting less active group/audience members to learn through the observation of their co-participants’ actions, selections, and reactions to the system’s and the instructor’s (here facilitator’s) feedback.

Louisa Ha and Lincoln James (1998) used business web sites as a test bed for assessing the value of interactivity in accommodating individual differences in communication needs. In order to achieve this, they perceived interactivity to consist of five dimensions: playfulness (providing games and curiosity arousal devices), choice (availability of unrestrained navigation), connectedness (feeling of being able to link to the outside world and to broaden one’s experience), information collection (willingness to provide information), and reciprocal communication (direct two-way exchange of messages). Although Ha and James’ dimensions originated from the world of the Internet, most of them can be aptly applied to other interactive technologies, such as our designed VE which employs gaming devices (playfulness), user navigation (choice), direct action feedback (reciprocal communication), and social presence (connectedness); a detailed description of the system can be found in Chapter 3.

In one of the most concise definitions of interactivity, Spiro Kiousis (2002) substantiated that interactivity is operationally composed of three principal elements: structure of technology (including speed, range, timing flexibility, and sensory complexity), communication context (including third-order dependency and social presence), and user perception (including proximity, sensory activation, perceived speed, and telepresence). With this framework Kiousis adopted various ideas from diverse disciplines tampering with the concept of interactivity, in order to provide an explication which can be broadly used by researchers in future investigations. While most of the common points with previously mentioned dimensions are obvious, maybe the most extensive similarities can be found with Jonathan Steuer’s definition of interactivity as a dimension determining telepresence. More specifically, Steuer (1992) recognized three primary factors that contribute to interactivity: speed (the rate at which input can be assimilated into the mediated environment), range (the number of possibilities for action at any given time), and mapping (the system’s ability to map its controls to changes in the mediated environment). These factors have clear implications in VEs, where real-time interaction (the highest value for speed), rich interactive content (many options for acting on the environment), and multi-modal interfaces (a variety of means to control changes in the environment) play a paramount role.
Another taxonomy inclined more towards interactivity in VR narrative was provided by Marie-Laure Ryan (2001), who interpreted the term as changes in conditions determined by the user’s input. Ryan distinguished four strategic forms of interactivity on the basis of two binary pairs: internal/external (user as either an avatar inhabiting or a god controlling the fictional world) and exploratory/ontological (user’s actions aim at either mere exploration or defining the fate of the virtual world). The four derivative forms grading the user’s relation to the virtual world are: external-exploratory (the user discovers the world without participating in it, e.g. puzzle or quiz games), internal-exploratory (the user is embodied in the virtual world but her actions have no bearing on the narrative events, e.g. Myst-like games\(^\text{13}\)), external-ontological (the user pulls the strings of the characters and makes decisions like an omnipotent god, e.g. simulation games), and internal-ontological (the user is cast as a character who determines his own fate by acting within the time and space of the fictional world, e.g. action and adventure games). The latter type is the one employed in our game design approach, as we feel that direct agency in the virtual world bears a positive impact on learning and engagement (more in Section 2.4 about Serious Games).

Closely related to Ryan’s forms of interactivity resides the taxonomy proposed by Narcís Parés (1999: cited in Parés & Parés, 2001) for defining interaction in artistic VR applications. This general but concise framework distinguishes interaction as explorative (ability to navigate freely in a VE), manipulative (ability to manipulate objects within the VE), and contributive (ability to alter the environment itself, either in form or functionality). We consider this kind of categorizing interaction in VEs quite succinct and a perfect match for the interaction-driven strategy chosen for our multiuser VR game design, thus this tripartite definition of interactivity will be used for the purposes of this research.

Lastly, since our proposed integrated schema can be primarily applied in and used by visitors of public spaces of informal education, we should not omit to provide a framework for planning and assessing the effectiveness of this interactive experience. Such a framework, as proposed by Adams and Moussouri (2002), includes five themes: multi-sensory dialogue, exploration, and discovery (engage visitors in problem-solving and foster/stimulate creativity), cultural connections (place visitors in context and make them comprehend how they fit within the culture, community, and family), empowerment (facilitate visitors in the construction of their own

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\(^{13}\) Myst is a famous first-person graphic adventure game released by Brøderbund in 1993, where the user explores a fantasy island with the quest of solving certain puzzles in order to crack a mystery.
experience by eliciting prior knowledge), *uniqueness* (focus on the attributes that make the experience unique and memorable), and *construction of meaning* (embrace visitors as part of their social group and facilitate social learning). These values are in total harmony with the desirable properties of informal education settings as seen in Section 2.1.3; hence our efforts will focus on integrating them in the group interaction design of the implemented VR experience.

### 2.2.3 Interactivity and Learning

#### 2.2.3.1 Theoretical approaches

Interactivity is widely believed to bear significant learning value in educational practice. As an intrinsic feature of information and communication technologies (ICT), which penetrated schools, homes, museums, and LBEs over the last two decades, interactivity is considered to enhance learning through an integration of cognitive and social interactions (the latter touching on collaboration, reviewed further in Section 2.3). Such technologies include multimedia applications, network systems, the Internet, and more recently virtual reality environments. Most of these resources employ interactive features as a means to enable richer dissemination from teachers/educators and easier assimilation by students/learners of the educational content.

The outbreak of multimedia applications development in the beginning of the 1990s, was instigated by Geoffrey R. Amthor’s widely cited finding that people retain about twenty percent of what they hear, forty percent of what they see and hear, and seventy-five percent of what they see, hear and do (Amthor, 1992). This view supports Papert’s general intellectual position in his seminal book *Mindstorms – Children, Computers and Powerful Ideas* that “the best learning takes place when the learner takes charge” (Papert, 1980b, p. 214). Another advocate of the significance of interactivity in learning is Philip Barker, who stated that “interactive learning is a necessary and fundamental mechanism for knowledge acquisition and the development of both cognitive and physical skills” (Barker, 1994, p. 1). According to Barker, knowledge acquisition and skill development could be based upon the provision of conventional computer-based training (CBT) or computer-enhanced learning (CEL); processes which usually involve the use of interactive learning environments (ILEs).

However, mere use of interactivity is not by itself enough to guarantee effective learning. Despite the hype on the positive impact of interactivity in CEL, there have been some adverse
opinions questioning its effectiveness. Rose (1999) emphasizes interactivity’s lack of “denotive value” by stating that “the concept of interactivity has become so firmly entrenched within the discourse of educational computing that it is a truism to say that instructional software is interactive and that interactivity promotes learning, and a kind of heresy to dispute it” (p. 43). Other research efforts to deconstruct interactivity’s efficacy in educational settings have also revealed the unfulfillment of excess expectations. A survey presenting the views of researchers, teachers and teacher educators in the UK on the ways that interactive multimedia can enhance teaching and learning outcomes, revealed the limitations and negative aspects of some elements of ICT use in schools (Haydn, 2006). Problems reported include the inconsistent relationship between computer use and student achievement, the inappropriate use of new technology (e.g., using a whiteboard to teach humanities subjects), the teachers’ lack of training to use software efficiently, and the tendency of learners to waste time browsing/searching the Internet or CD-ROMs, which tended to sidestep rather than aid the challenge of learning.

This outcry of interactivity’s questionable impact on educational practice can be refuted by moving the focus of interactivity away from the medium’s operations (functional interactivity) and towards the learner’s cognition (cognitive interactivity). This is underpinned by Jonassen’s view that “because knowledge is mediated through student thought processes and not the medium itself, instructional design should focus on the thought processes activated by learning activities” (Jonassen, 1988, p. 155). It is the careful design of instructional information that promotes meaningful interactions and, as a result, supports students’ cognitive processes. Along the same lines Kennedy (2004) proposed the Cognitive Interaction Model of multimedia interactivity, according to which interactivity is described as a continuous dynamic interplay between instructional events (design and content), behavioral processes (actions and activities), and cognitive processes. This model, in which functional interactivity is the mediator between instructional information and the students’ cognitive processes, bears the potential benefits of increased intrinsic motivation and more favorable learning outcomes.

Similarly, Aldrich et al. (1998), in an attempt to help teachers assess the educational value of CD-ROMs, have underscored the importance of “moving the emphasis away from the level of physical interactivity at the interface (i.e., button presses and mouse clicks) to a consideration of cognitive interactivity (i.e., the learning activities which are supported when interacting with the software)” (p. 331). The beneficial effects of interactions between the learner and instructional
tasks at a cognitive level have also been accentuated for online learning, by means of promoting decision-making and problem-solving skills, enabling asynchronous discussions, generating experience variations, and employing demonstrations, visualizations, simulations, and investigations (Lander, 1999). Gaming is also considered by some to be the perfect initiator for shifting the focal point of interactivity away from the capabilities of the technology and towards the skills of the people, in an attempt to facilitate learning by complementing existent teaching tools and methods (DeKanter, 2005). Cognitive interactivity, i.e., the learning activities of an audience interacting with a game in an immersive VE, is also the focus of the interaction paradigm of this research.

Furthermore, Rod Sims (2000) revisited the relationships between interactive constructs and learning theories, taking into account the four major dimensions of the interactive learning process: the learners, the content, the pedagogy, and the context. He used those dimensions in order to support the position that interactivity constructs can be considered as outcomes of educational research rather than a manifestation of the technology being employed. In an attempt to provide a viable solution for, what he calls, the “interactive conundrum,” Sims sustained that “it is the theoretical frameworks, which provide a guide for interactivity, that will enable us to achieve success in our teaching and learning endeavours” (p. 51). The theoretical framework of our research, which is grounded on the assumption that it is through engaging a group of learners in unique interactive and social experiences using exploratory activities that learning is best achieved in informal education settings, is explicated in the next Chapter.

2.2.3.2 Examples from existing research

Despite the abundant aforementioned frameworks and theories praising the educational value of interactivity, very few empirical studies have been done so far to assess the plausibility of those claims. One attempt to investigate whether adding interactivity to diagrammatic representations aids learning in the context of geometry teaching, focused on the extent to which 3D interactive diagrams facilitate the comprehension of stereographic projection, a geometry concept usually taught using 2D diagrams (Otero, Rogers, & Du Boulay, 2001). The hypothesis of this study, that the more interactive ILEs will provide better immediate learning results (i.e., answering more multiple-choice questions about the related concepts) than the less interactive ones, was tested using four ILEs with different representations and varied levels of interactivity. The results led to
the conclusion that the mere addition of interactivity, either to the 2D or the 3D representations, did not provide the expected learning gains. However, it was noted that this was an exploratory study and additional investigation was required, since learning seemed to be affected by the appropriateness of the subject’s representation, the lack of proper feedback and assistance, and other learner-specific factors.

Another study assessing the effectiveness of interactivity on Web-based educational software (courseware) containing algorithm animations and data structure visualizations has shown that, although interactivity can potentially increase the amount of time students spend using such courseware, this added time does not necessarily contribute to increased understanding of the material presented (Jarc, 1999). The evaluation of this study indicated that the students who used the interactive version spent significantly more time using it than those who used the non-interactive one and scored better on several of the questions testing the more difficult questions, but performed more poorly overall. The most possible explanation provided by the researcher was that the students are carried away by the entertaining nature of the interactive version and therefore spend more time using it, but do not achieve the desired result (i.e., learning the topics). As an overall conclusion, this study claims that interactivity might be an asset to learning when properly used.

A more recent study, investigating user interaction in immersive VEs, focused on the role and the effect of interactivity on conceptual change and learning, in primary school children (Roussou, 2006). The main experiment of this study, which was conducted with a VE designed to simulate a “virtual playground” and focused on the presentation of problems in mathematical fractions, employed three conditions with different levels of interactivity: an interactive VR, a passive (or guided) VR, and a non-VR condition. The evaluation phase revealed that interactivity promoted skill and problem solving and provided opportunities for contradictions to emerge but could not necessarily lead to the resolution of these contradictions, nor could it eventually account for conceptual change. Instead, it was the passive VR form of experience (served by the guidance of a virtual robot) that showed potential to support resolution of contradictions in a way that encouraged reflection of the underlying conceptual learning problems. What is ultimately suggested by the findings of this research is that the social structure (represented by the robot and the observer) may be more important than interactivity, on its own, in supporting the process from problem solving to the making of meaning.
There are quite a few fundamental differences between the ILEs used in the above studies and the VE investigated in this research. Maybe the most prominent difference is the number of people interacting at the same time: those studies totally lack the feature of multi-user collaboration, while our research focuses on the simultaneous collaborative interaction of groups and large audiences. Secondly, those studies have tested learning in the context of science education, clearly guided towards teaching specific scientific concepts (conceptual learning), and in most lacking game-like properties. In our case, emphasis is on the dissemination of cultural heritage information (factual and procedural learning) through collaborative play. Thirdly, these were controlled studies, assessing formal education concepts in research laboratories; our research is guided towards a more ecological approach, assessing every day knowledge in museums and similar spaces of informal learning. Lastly, the target group of these studies (except the last one) was undergraduate and graduate university students, avoiding some of the difficulties encountered in conducting empirical evaluations with school-age children.

As stated before, the focus of this research is to provide learning in a group of middle school students (11 to 13 years old) by exploiting interactive technology. However, it is not the technology that we will strive to assess in the evaluation stage of this research but rather the efficacy of the implemented interactive learning activities; namely, the cognitive interactivity. We believe that the power of interactivity in education lies not within the technologies being employed (e.g., devices, interfaces, etc.) but rather in the ways that interactive technology can influence instructional design and help in defining learning strategies for particular students, with specific tasks in distinct contexts (Kozma, 1994). Hence, our efforts are guided towards developing and assessing the proposed integrated schema which we assume can satisfy the learning needs of school-age children visiting informal education settings (the students), playing together engaging games (the tasks), in virtual reality environments (the contexts). In this developmental approach focusing on the creative exploitation, integration, and improvement of existent technologies in order to enhance student communication, learning, and performance (T. C. Reeves, 1999), audience interactivity constitutes a pivotal component.

2.2.4 Audience Interactivity

Audience interactivity refers to the process that a large number of collocated people engages in interacting meaningfully with the content presented to them on a large-scale display. The term is
relatively unexplored and its scant uses have, by no means, derived by any formal research practices, nor undergone any formative evaluation, especially in the informal learning context of the museum. However, there have been quite a few different ways and technologies for allowing a large number of people to vote for their favorable response in multiple choice questions, or influence the flow of a movie or the course of a game.

2.2.4.1 Technologies for audience interaction

Maybe the most common use of audience participation in training and education can be found in the audience response systems (ARSs), which although developed in the mid-1960s became widely available in the beginning of the new millennium. ARSs are electronic remote devices which permit students (or trainees) in a classroom to respond to multiple-choice questions displayed on a screen. The results are instantly collected, summarized, and presented to the class in visual format. Although responses are usually anonymous to peers, the teacher can associate ARS devices with individual students for testing purposes, or exploit the feedback in order to orchestrate peer or classroom discussion about concepts being covered (Kay & LeSage, 2009). These systems, due to their broad application in school classrooms, are also called interactive classroom communication systems (ICCSs).

ARSs have been quite extensively surveyed for their educational value and found to bear significant benefits by means of: infusing interactivity into a standard lecture; increasing student participation, attendance, and learning; improving teaching and learning by providing immediate feedback; ascertaining student attributes and opinions; constituting faculty more favorably perceivable by students; and facilitating in-person self-assessment modules for maintenance of certification (J. Collins, 2008). Nonetheless, there have also been reported some limitations of ARSs: commercially available systems are generally bulky, expensive, and not easily transportable; effectiveness depends on instructor competence and equipment reliability; questioning reduces time for lecture content; faculty time to develop questions and prepare discussion; and some students’ negative perception of ARSs as playing games. For these reasons we believe that bringing ARS technology in the context of informal education settings relieves teachers from the added labor of preparing the material and maintaining the system, as well as students from the “guilt” that valuable lecture time is wasted for game-like activities.
There have been some attempts in the past for incorporating mass interaction techniques in the mass media (radio, television) and public attractions sites (theaters, cinema and planetariums). The former types, which include interactive TV services\(^\text{14}\), are not within the scope of this research since information provided is predetermined, interaction is basically one-way (from the viewer to the program provider), and the audience is not collocated but rather distributed. The latter types include cases where interactivity ranges from mere branching decisions or replying to multiple-choice questions to playing simple games or navigating in virtual worlds. Interaction is achieved through the use of keypads attached to the auditorium’s armchairs, reflective paddles, laser pointers, and/or motion capture techniques.

The simplest kind of collocated audience interaction\(^\text{15}\) was devised for allowing the audience in a theater or cinema to control the flow of the play or movie. This kind of providing a choice to spectators to alter the scenario was initially applied in theatrical performances, where the audience could influence the plot by either taking part in the drama or through a collective vote. Audience participation in the cinema was pioneered during the mid 1970’s by “The Rocky Horror Picture Show,” in which members of the audience were instigated to act and dress like the actors, speak their lines, sing the musical’s songs, and even throw various items at the screen or at each other in specific points of the movie\(^\text{16}\). However, such examples intended for entertainment purposes only reside out of the scope of this research, which focuses on computer-mediated group interaction in public spaces of informal learning.

Advancements in image processing technology allowed researchers to invent innovative ways of audience participation. Such an apparatus, which was originally presented at the SIGGRAPH Electronic Theater in 1991 by Loren and Rachel Carpenter, is the Cinematrix Interactive Entertainment System® (Cinematrix, 1991). This wireless “mouse for the masses,” as it has been called, allows a large number of people to interact with real-time content through the use of retro-reflective paddles. Audience members engage in group entertainment experiences simply by turning their paddles one way or the other. Similar technologies have been developed since then, based on the same principles of computer vision like motion analysis and shadow tracking, and primarily used in art installations and entertainment. Other less physical types of

\(^{14}\) A quite complete list of interactive TV services can be found in (Heeter, 2000)
\(^{15}\) From this point on when using the term audience interaction we strictly refer to a collocated audience
\(^{16}\) Information drawn from a Wikipedia article about the film’s pop culture; retrieved on October 2014 from: http://en.wikipedia.org/wiki/The_Rocky_Horror_Picture_Show_cult_following
audience interaction, but equally intuitive, involve the use of keypads and joysticks, which are the devices used in this study. Finally, various other experimental devices have been proposed, mainly to serve as audience voting systems\(^\text{17}\), but have not undergone any formal testing either in laboratories or in real conditions.

2.2.4.2 Examples and limitations

Most audience interactivity techniques have been exploited for providing the audience with a medium to express their opinion about something, like voting for a set of questions or deciding between two or more paths of a prerecorded story. Furthermore, the overwhelming majority of their implementations have focused on art, entertainment, and games with no educational value whatsoever. In the following paragraphs, we are going to refer to some of the work being conducted in this field, including paradigms that satisfy all or most of the components of the proposed integrated schema (i.e., collaboration and games in virtual environments), also referring to the objective of these experiences (i.e., entertainment, learning, or both) and the inclusion of any formal or informal evaluation.

The most popular technology employed so far for allowing the members of a large audience to participate in shared interactive experiences is computer vision. Dan Maynes-Aminzade, Randy Pausch and Steve Seitz (2002) have experimented with such technology in order to develop games for large audiences (from 150 to 600 people). The implemented applications, based on audience movement tracking, object shadow tracking, and laser pointer tracking, were mainly used as entertaining pre-shows in large-scale participation events like conferences, movie premieres, and various festivals. Although this work has solely focused on adult audience entertainment in conventional auditoriums and does not include any kind of evaluation method, we agree with its conclusions that “the greatest challenge lies not in developing the technology for audience interaction, but in designing engaging activities” (p. 19).

Other researchers have paid more attention to creating interactive art through the use of motion analysis (Nguyen et al., 2006) or motion sensing (Loke & Robertson, 2009) of large audiences in public spaces. The former study utilized video analysis systems for facilitating interaction with art in complex environments. The trial installations (named *Music, Volleyball*,

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\(^{17}\) Example are the voting systems proposed for the sports events of the Olympic Games 2004, by the participants of the Student Competition taking place at the CHI 2004 Conference in Vienna, Austria.
2.2 Interactivity

*Hockey,* and *Spray Paint*) were done in a lecture theatre with 25 adult volunteers, and attempted to foster collaboration and competition through either body movement or by waving cardboard squares. The latter study used video-based, motion-sensing technology as a means of developing a set of design representations of moving bodies in artistic and cultural environments. *Bystander* was the name of the multiuser, interactive, immersive artwork implemented in order to explicitly address audience behaviors expressed in social interaction situations, emerging in museum and gallery environments. More specifically, audience configuration and activity in the artistic space (e.g., presence, movement, stillness, density, proximity, etc.) influenced the type and pace of the projected content. As defined by the work’s artists “audience interactivity […] was based on cultivating a contemplative audience engagement with a *spirit-world* of images, texts and sounds” (p. 398). Both of these research efforts aim at allowing members of an adult audience to interact with artwork using physical movements, purely for entertainment purposes.

Audience interactivity has also been considered in the context of urban environments, as a means of collaborative play. O’Hara et al. (2008) have investigated the implications of spectatorship, audience, and performance in a collaborative game called *Red Nose,* where people participate in outdoor public spaces by pushing on “virtual blobs” displayed on a large screen. Interesting findings of this research include the significance of performing for and being motivated by an audience, the efficient coordination and collaboration of non-related people, and the importance of a compere (or interaction orchestrator) for enhancing the audience engagement through motivation, explanation, and commentary. A similar implementation, but on a much larger scale, is the real-time interactive game *Squidball,* which aimed at providing a unique and energetic experience for an audience of up to 4,000 people at SIGGRAPH 2004 (Bregler et al., 2005). The scope of this work was to examine the intricacies of large-scale game design and observe the social dynamics of mass audiences involved in hitting retro-reflective balls across an auditorium of 240 x 240 feet and watching the result on a projection screen. Like the previous work, the context may totally differ from our research but some useful conclusions were drawn concerning the overall audience experience: players should be allowed to make mistakes and learn from them, gameplay difficulty should progress incrementally, people had problems dividing their attention between the screen and the activity, as well as coordinating their physical actions with the projected result on the screen.
Most of these techniques may be really promising for the engagement of small or large audiences in entertaining experiences, either at outdoor or indoor public spaces; however, the technology involved imposes far too many limitations. The image analysis and computer vision techniques employed by those applications for enabling audience interaction suffer from:

- **Lighting**: projection screens demand relatively dim lighting conditions, which hinder the process of capturing clear images from the camera.

- **Positioning**: people who are sitting at distant positions from the camera(s) have a less pronounced effect on the interaction.

- **Audience distribution**: uneven audience distribution causes uneven degrees of control and may even inhibit interaction.

- **Autonomy**: members of the audience are not individually recognized by the system (an exception to this is Cinematrix), which causes disbelief about the degree of personal impact on the formation of the content.

- **Calibration**: most of those systems demand a calibration phase which cannot always be seamlessly integrated with the show.

These issues caused by the use of computer vision techniques can be surpassed by utilizing dedicated devices (e.g., keypads and joysticks attached to armchairs in an auditorium, handheld devices like tablets and PDAs, etc.) This allows every member of the audience to actively participate in the interactive activities and influence, individually or collaboratively, the course of action. Again, these devices have been extensively used in LBEs, like theme parks, leisure centers, and movie theaters, for mass entertainment purposes\(^\text{18}\) with none to minimal educational value. Shows presented in such spaces mobilize a combination of technologies (e.g., audience interaction, spatial sound, 3D stereoscopy, etc.) in order to provide unique family experiences, by bridging the cinema and video game industries (Chiwy, 2000). Exceptional academic endeavors on this convergence were done by the Interactive Cinema Group\(^\text{19}\) of the MIT Media Laboratory, which focused on formal structures, construction methods, and the social impact of highly distributed

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\(^{18}\) "de pinxi" is a renowned company offering such mass entertainment experiences in interactive theaters. More information at http://www.depinxi.be/ [last accessed: May 2014]

\(^{19}\) This research group was active from 1987-2004, then renamed to Media Fabrics, and ceased its activity on 2008. More information at http://ic.media.mit.edu/ [last accessed: October 2014]
motion video stories. The vision of the Group's director Glorianna Davenport was “a theater experience in which the audience controls the story as a group”, and where “a storytelling database could allow a movie experience to be generated at run time.” (Davenport, 2000, p. 82).

2.2.4.3 Audience interactivity for learning

Nonetheless, very few attempts have been made so far that take advantage of the available technology in order to provide interactive learning experiences for a classroom sized (or larger) audience of students. Exceptions are the educational shows developed at the Foundation of the Hellenic World and presented at the VR dome theater of the Cultural Center “Hellenic Cosmos”, in Athens, Greece. These shows, mainly addressed mainly at elementary and middle school students, exploit the individual interaction devices attached on every seat (keypad and joystick) in order to enable young visitors to vote for their desired route in the virtual world (e.g., the Ancient Agora of Athens), decide which enemy of the state should be banned for ten years into exile, complete the restoration of an ancient building through a Tetris-like game, or reply to questions of a quiz game on climatic change (Christopoulos, Apostolellis, & Onasiadis, 2009). Although these paradigms of audience interactivity are fairly simple and have not undergone any formal evaluation for their learning efficacy, the authors have noticed, through observations, a high degree of participation and content on behalf of school aged audiences.

**Figure 2-2.** Joypad setups on seat armrests can be used for ‘majority rule’ interaction, such as navigation, trivia quiz games, or other audience response polling techniques (Christopoulos et al., 2009).
Another notable work on group interaction for educational purposes has been presented by the Studio for Creative Inquiry at Carnegie Mellon (Dannenberg & Fisher, 2001). This study included two productions on science education and employed Cinematrix paddles to selectively present information about cell biology and the brain, to an audience of 150 people situated in a planetarium. Although this work was very promising, as concluded by informal observations, there was no formal evaluation carried out to assess the efficacy of mass interaction for facilitating learning. Moreover, the researchers focused on ways to understand audience behavior effects like group dynamics, nearest neighbor effects, and changes in response time, as opposed to assessing the learning gains of their audience members.

Figure 2-3. Images from the multimedia planetarium show Gray Matters: The Brain Movie (Dannenberg & Fisher, 2001); audience participants use Cinematrix paddles to control individually fish avatars (left), activate collaboratively a neuron (middle), and control individually one three-sided puzzle piece trying to form a single image (right).

The Allosphere is a spherical immersive virtual display that can accommodate approximately 20 people on the bridge that runs through the middle of the sphere. Researchers at the Media Arts and Technology Program at UCSB developed an interactive, stereoscopic, immersive virtual world from fMRI brain data installed in the Allosphere, called the Allobrain Project (Thompson et al., 2009). The scope of this and other projects implemented in the Allosphere is not to assess learning per se (e.g., measuring the impact of collaborative interaction on the comprehension of visual representations), but still constitutes a significant example of audience interactivity and VR application for education. Nonetheless, we found one of their observations very important; that the use of familiar devices such as gamepads or joysticks tend to encourage a distinctive “game-play” style of interaction. This can have significant implications when designing audience interaction metaphors, especially for students.
2.2 Interactivity

Figure 2-4. The Allosphere (Thompson et al., 2009) uses three different types of interaction techniques to allow participants to interact with fMRI data (from top to bottom): the Visual Navigator (for the Allobrain project), the Sphere Spatializer, and electric-field sensors connected on the bridge’s hand-rails.

However, the aforementioned types of audience interaction are tightly coupled with the technology (i.e., a digital projection displays with interactive capabilities), which significantly restricts the types of educational applications offered to school classrooms visiting the hosting public spaces. Thus, many educators, museologists, and exhibition designers resort to mobile devices for enhancing museum visits through multiuser interactive experiences. In most cases these involve scavenger hunt types of games, where family members have to move throughout the museum space in order to collect information about exhibits, using handheld devices and RFID-enabled exhibits. The abundant examples that exist so far (Asai, 2010; Danks, Goodchild, Rodriguez-Echavarria, Arnold, & Griffiths, 2007; Klopfer, Perry, Squire, Jan, & Steinkuehler, 2005; Legn, Hindmarsh, Luff, & Heath, 2007; Yiannoutsou & Avouris, 2012) aim mainly to engage children and their parents in innovative learning experiences, where the parent acts as the facilitator of the collaborative activities. However, both the specific audience (i.e., family members) but even more the physical movement of visitors in the museum space and interaction with exhibition artefacts are outside the scope of the current researched. The few examples that involve group collaboration using games and/or employing VEs in museums spaces will be reviewed in Section 2.4.3 and Section 2.5.3, respectively.
The audience in interactive experiences, like the ones mentioned above, interchangeably assimilates the roles of both active participators, as well as passive spectators. Hence, we consider spectatorship to greatly influence the social dynamics of the audience, and consequently affect the learning benefits acquired from the overall experience. Stuart Reeves et al. (2005) have focused on the ways in which interaction in public spaces affects and is affected by spectators, and proposed four general approaches to designing public interfaces. Thus, interactivity in public spaces can be considered as secretive, expressive, magical, or suspenseful according to the degree that interaction effects and manipulations are hidden from or amplified to spectators. Orchestration by human agents (i.e., content experts, guides, or docents) is also suggested to play a vital role in shaping the spectator experience, which according to Brenda Laurel (1993) resembles human contributions (e.g. director, actors, technicians, etc.) in the production of successful theatrical performances. We consider the contribution of an orchestrator as an important factor in facilitating audience interaction through the interchange of all four modes of Reeves’ taxonomy, in order to provide a unique learning and entertaining experience.

Finally, some scholars emphasized the importance of providing choice and control to the audience in forming a customized experience, through the use of emerging technologies. Rob Cover (2006) suggested a re-conceptualization of the author-text-audience relationship, and put forward interactivity as a form of audience participation which can satisfy the audience’s “strongly-held and culturally-based desire to participate in the creation and transformation of the text that has effectively been denied by previous technologies of media production and distribution.” (p. 144). His view totally coincides with the inactive nature of group entertainment that visionary Marshall MacLuhan had exclaimed against, by stating that “though the mass audience can be used as a creative participating force, it is, instead, merely given packages of passive entertainment” (McLuhan, 1967; as cited in Maynes-Aminzade et al., 2002, p. 19). Davenport advocates that electronic media can shape new “societies of audience” where people can awaken their thinking, and thus—we believe—evoke learning, by sharing “not only a text but the process of understanding that text” (Davenport, 1997, p. 296).

2.2.5 Section Summary

Definitions and dimensions of interactivity have been initially reviewed as seen through the eyes of many scholars and researchers from a diverse range of disciplines (i.e., communication, media,
and computer science). The basic distinction of interactivity as proposed by those definitions is interactivity as a property of the medium (functional interactivity) and interactivity as perceived by the user (perceived interactivity). Also, the assumed significance of engaging intellectually and emotionally the visitors of informal education settings in interactive experiences, combined with the social interaction and social presence affordances offered by their collocation in these public spaces, motivated our research decision to investigate group/audience collaboration as a promoter of learning and engagement in such venues.

We have also reviewed the learning benefits of interactivity as theorized or evaluated by scholars and tried to identify common points and differences compared to our research. The outcome of this survey was to select cognitive interactivity as the “holy grail” of our research and, thus, muster our efforts on developing appropriate learning activities, interacting with which can activate the thought processes of our young audience’s members. In order to build those activities in an integrated VR experience of informal learning, we will adopt the interaction-driven design strategy for VR applications proposed by Parés and Parés (2001), and draw ideas for planning and assessing the designed interactive experience from the framework proposed by Adams and Moussouri (2002). In the final part, we scrutinized the history and main practices of audience interactivity, which allowed us to identify a considerable gap in studies related to the exploitation of this form of group interaction for learning, and especially a complete lack of evaluation methods and implementations.

2.3 Collaborative Learning

The social context within which learning takes place has long been praised for its educative character. Philosophers and educators like John Dewey (1916) supported the view that the young acquire deep and intimate knowledge through their participation in the activities of the various groups that they belong to; as opposed to the conventional stance of education that learning occurs isolated from the environment producing knowledge inscribed in individual minds. Collaborative learning embraces this more situated view of learning which occurs through meaning negotiation carried out in the social world rather than in the individuals’ heads (Stahl, Koschmann, & Suthers, 2006).

In this section we briefly refer to the theoretical approaches that have guided the evolution of collaborative learning and carefully review some typical examples of CSCL applications. This
Chapter II – Background and Related Work

will allow us to recognize the weak and strong points of those endeavors, drawing some useful conclusions on their applicability to the design of our integrated schema.

2.3.1 Theoretical Approaches

Collaboration has often been confused with cooperation and both terms have been used interchangeably by scholars in the past. In this research, we follow the distinction made by Jeremy Roschelle and Stephanie Teasley (Roschelle & Teasley, 1995) according to which cooperation “is accomplished by the division of labor among participants, as an activity where each person is responsible for a portion of the problem solving,” whereas collaboration involves “the mutual engagement of participants in a coordinated effort to solve the problem together.” (p. 70). Their theory proposes that collaborative problem solving takes place in a negotiated and shared conceptual space (what they call a Joint Problem Space), constructed via engaging in shared situations, utterances, and activities. This view contrasts the beliefs of traditional cognitive psychology which examines knowledge constructed in a group as the aggregation of individual cognitive processes.

Collaborative learning occurs as a side-effect of these problem-solving situations and activities, and is measured by the elicitation of new knowledge or by the improvement of problem-solving performance (Dillenbourg, 1999). Moreover, some years earlier, Pierre Dillenbourg et al. (1996) had identified the inclination of research to depart from the dominant position in the 1970s and early 1980s that social interaction was seen more as a background for individual activity, and move towards the socially constructed properties of the interaction with the group itself as the unit of analysis. He referred to how educational theories have shaped the evolution of collaborative learning from the Piagetian socio-cognitive approach, which focused on the individual development in the context of social interaction, to the Vygotskian socio-cultural view, which gave emphasis to the casual relationship between social interaction and individual cognitive change. Evaluation methods in both of these approaches greatly differ from our research paradigm in three aspects: group size, time span, and environment. More specifically, socio-cognitive experiments mainly involved two subjects of approximately the same age, while socio-cultural settings concerned adult-child pairs; in both cases the environment was either a laboratory or a classroom and experiments involved sessions of either a few hours or a period of one year, respectively.
2.3 Collaborative Learning

The shared cognition approach, deeply intertwined with the situated cognition theory (J. S. Brown et al., 1989), is more suited to our work which aims at examining the (collaborative) learning outcomes of a group immersed in a virtual environment. This is due to the fact that the concept of shared cognition considers the environment as an integral part of cognitive activity, placing the focus largely on the social context of this environment, i.e., the social communities in which the collaborators participate. This shift to the group unit of analysis coincides with the theory of situated learning (Lave & Wenger, 1991), which addresses learning as a process of socially organized meaning construction, and the collaborative knowledge-building communities (Scardamalia & Bereiter, 1996), which provide informal knowledge by supporting the process of expertise (intentional learning) as it applies to competence and understanding.

The extensive use of computers in classrooms and the wide accessibility of the Internet in education during the 1990s, pushed researchers to cease the isolated learning model of schooling and exploit technology for the facilitation of collaboration. This trend gave rise to the field of Computer-Supported Collaborative Learning (CSCL), and the development of software and applications that could bring learners together and offer creative activities of intellectual exploration and social interaction (Stahl et al., 2006). Motivated by the sociocultural theories of learning, these efforts aim at supporting interpersonal collaboration, by providing mediation for communication, scaffolding, and directed discourse as a means of shared knowledge construction.

CSCL as a process of shared knowledge construction (or meaning making) is an intersubjective occurrence which demands intersubjective assessment rather than traditional psychological methods, like statistical correlations, to assure its acceptability (Stahl, 2002). Furthermore, Gerry Stahl (2006) used the term group cognition to describe intersubjective learning occurring in small groups (what he called “the engines of knowledge building”), where shared construction of meaning is most visible and is “internalized by their members as individual learning and externalized in their communities as certifiable knowledge.” (p.16). What is more, different scholars hailed the visibility, and consequently availability for research, of collaborative learning processes occurring in CSCL interactions (Stahl, 2002, 2006), such as language as a shared referent between social partners (Roschelle & Teasley, 1995), negotiation and argumentation as conversation models (Dillenbourg et al., 1996), and utterance grounding mechanisms (Dillenbourg & Traum, 1999).
However, some of the aforementioned conditions and ascertainments about the application and confirmation of CSCL cannot be utilized in all the studies of the current research due to various design constraints. More specifically, the collaboration environment (i.e., museum space), the group size (i.e., either three or around twenty students), and the type of interaction (i.e. group or audience-interaction protocol) might inhibit strategies of oral negotiation, which are most common in the majority of CSCL research. This fact forces us to follow an alternative course for the evaluation of our prototype, which will include, along with observation methodologies, a computer generated log file with the recording of the participants’ collaborative interactions. A detailed analysis of the research methodology can be found in Chapter 4.

Where most of the theorists mentioned above converge is a consensus on the fact that CSCL practices should focus on the mediating interactions that can trigger collaborative learning, rather than establishing parameters for effective collaboration. Stahl et al. (2006) stated that collaborative meaning-making is an interactional achievement that greatly hinges upon the design of appropriate technological artifacts that mediate interaction. Even more eloquently, Dillenbourg et al. (1996) articulated that “we should stop using the word ‘collaboration’ in general and start referring only to precise categories of interactions” (p. 21). Our audience interaction paradigm is such a category of mediating technology in service of group (collaborative) learning.

### 2.3.2 CSCL Research

Research on CSCL started by exploiting the advantages of network computing, such as broad accessibility and inter-connectivity by a large number of—usually—remotely located individuals. An abundance of studies has also been conducted in classrooms and included the use of desktop workstations connected through a network, where students had to engage in collaborative activities over a long period of time (e.g., a course of one year). Some cases have even utilized asynchronous collaboration practices where participants could interact at their own pace, mainly by using Internet services (e.g., e-mail, chat programs, forums, etc.); the continuation of this practice is what we now call distance education. However, in this part we are going to examine only research cases which concern synchronous, collocated collaboration of two or more participants (in most cases children), preferably on a shared display and for a short session, having as an objective the elicitation of learning.
Collaborative techniques have been initially scrutinized in the context of cooperative work. Attempts were guided towards building multiuser interfaces that allowed the collaboration of two to six people in a meeting room, equipped with individual workstations and a large touch-sensitive screen for the coordinator (Stefik, Bobrow, Foster, Lanning, & Tatar, 1987). Such implementations followed the WYSIWIS (What You See Is What I See) abstraction and allowed multiuser collaboration in face-to-face meetings. Extensive research has been conducted on such real-time distributed groupware settings, where people work together from different computers, in order to provide support for effective collaboration. *Workspace awareness*, the up-to-the-minute understanding of another person’s interaction with the shared space (Gutwin & Greenberg, 1996), is believed to facilitate collaboration through coordinating activity, providing appropriate assistance, simplifying verbal communication, and managing movement between individual and shared workspace. Other endeavors included the provision of multiuser editing capabilities on a single screen, where multiple users (usually two) could simultaneously share, access, and alter the same text string or graphical object (Bier & Freeman, 1991).

The intrinsic desire of people, and especially children, to work together while being physically close to each other has shifted research practices towards models of co-present collaboration. Single Display Groupware (SDG) is such a model which enables collocated people to collaborate via a shared computer with a single display and the use of multiple input devices (Stewart, Bederson, & Druin, 1999). SDG applications have been exploited by researchers and educators as a means of encouraging collaboration with the intention of combining the educational role of learning collaborative skills with the affordance of as much control to the children-users as possible (Benford et al., 2000). This approach of encouraging collaboration instead of enforcing or enabling collaboration is believed to provide explicit motivation for the users to work together, by rewarding their collaborative activities with some kind of added benefit.

Practices of collaborative (or cooperative) learning have been broadly applied and evaluated in classrooms with admirably positive results (Bruckman, 1997; Inkpen, Ho-Ching, & Kuederle, 1999; D. W. Johnson, Skon, & Johnson, 1980; Scardamalia & Bereiter, 1996; Scott, Mandryk, & Inkpen, 2003; Slavin, 1980). More specifically, a study conducted in elementary or secondary classrooms revealed that cooperative learning methods account for increased student achievement, mutual concern among students, improved student self-esteem, and low-level (i.e., knowledge, calculation, application of principles) and high-level (i.e., problem analysis,
identification of concepts, judgment, evaluation) cognitive learning outcomes (Slavin, 1980). Also, cooperative learning has been shown to prevail over competitive or individualistic efforts in high problem-solving performance, by dint of allowing students to employ more effective strategies, and perceive higher level of peer support and encouragement for achievement (D. W. Johnson et al., 1980). Nonetheless, another study indicated that computer-supported competition triggers fundamentally similar collaborative learning processes to the ones observed in more cooperative contexts (Shaffer, 2004).

Other research efforts conducted in computer-supported classrooms involve the influential Computer Supported Intentional Learning Environments (CSILE) project, conducted by Bereiter and Scardamalia, who were concerned about the shallow and poorly motivated learning that takes place in schools. Thus, they proposed and examined the idea of learning in “knowledge-building communities”; i.e. communities of experts working on a research problem. Their evaluations indicated that students attending the CSILE classes excelled in depth of learning and reflection, awareness of what they have learned or need to learn, and in understanding learning itself as a process (Scardamalia & Bereiter, 1996). Furthermore, in the project “MOOSE Crossing” Amy Bruckman engaged 8-13 years old children in a networked, text-based, virtual world designed to be a constructionist learning environment, for a period of over one year. The analysis of this study revealed that construction activities in the virtual world helped children to create “a particularly special, intellectually engaging sort of community”, within which students were motivated and supported one another’s learning experiences (Bruckman, 1997). Even though these studies were carried out over a long period of time within formal education settings, we hypothesize that by providing opportunities for an audience of people to engage in collaborative interactions even for a short session, will promote a similar sense of belonging to a community and, potentially, leverage their learning capacity.

Besides research conducted in classrooms, there have been empirical studies which examined children’s collaborative activities in controlled environments, such as research labs. One such case which assessed the children’s level of engagement with three versions of a game (a paper-based version and a computer-based version with one or two mice) indicated that allowing multiple children to interact with the environment simultaneously, ensures that they are engaged in the computer-based learning activity (Inkpen et al., 1999). Similarly, children collaborating simultaneously in collocated environments availed themselves of greater engagement, sense of
2.3 Collaborative Learning

participation, and enjoyment of the activity, by concurrently interacting on a shared physical display as opposed to collaborating by sharing a virtual display (Scott et al., 2003). These findings emphasize the inherent characteristic of children to indulge in social interactions, a fact that will guide the design and implementation of our integrated schema.

All the above studies employed desktop computers in order to assess the efficacy of collaborative learning; however, more recently SDG systems have utilized physically large displays in order to accommodate a larger group of people. Examples of such devices are the DiamondTouch, a multi-user touch technology for tabletop front-projected displays (Dietz & Leigh, 2001), and the DynaWall, a computer-augmented wall (belonging to a category of hardware also known as roomware) consisting of a combination of three adjacent interactive whiteboards (Geißler, 1998). Both of these technologies, and similar ones, can accommodate a limited number of users (up to four and three users, respectively) and have been mainly used in the application of multiuser touch-sensing (Geißler, 1998), laser-pointing (J. Davis & Chen, 2002), and gestural interactions (Morris, Huang, Paepcke, & Winograd, 2006), especially for cooperative work.

However, in a more recent research which tested the efficiency of children’s collaboration using a tabletop display over the conventional manipulation of physical tools, preliminary evaluation has shown that children adopt assertive strategies in order to gain control and contribute to the shared space (Marshall et al., 2009). Corollary of this finding is the belief that children seek more control during their simultaneous interactions with computers and collaboration with other children, which—in part—justifies our assumption that there is a great need for group interaction activities, especially in venues which can accommodate classroom-sized audiences like museums.

The type of learning occurring in such venues should primarily be entertaining, in order to entice their young audiences by stirring their imagination and satisfying their need for social interaction. Their entertaining character and capacity to engage large audiences of people in collaborative play (Harris, 1998) should be exploited in favor of providing their young visitors with educative content and satisfying their learning needs. A novel research which experimented with collaborative play with the use of a human voice box by three participants (using their voices as a joystick) in order to solve maze puzzles, emphasized the importance of audience participation in heightening the players’ relationship to the physical and social space and, consequently, in forming a pleasing group experience (Niemeyer, Perkel, & Shaw, 2005). Moreover, this study
accentuated that effective teamwork is “a performance for an audience based on cross-functional behavior of individuals who are aware of a common goal” (p. 594). This statement totally converges with the motivational perspective of cooperative learning according to which group members, in an attempt to reach their personal goals (which lead to the common goal), must help and encourage their group mates to exert maximum efforts and do whatever is needed in order for the group to reach its goal (Slavin, 1995).

Besides the aforementioned attempts to study collaboration in classrooms and public spaces using desktop, tabletop or wall-mounted displays, quite a few researchers have mobilized VR as leverage for collaborative work and learning. Departure from the initial desktop VR setups, which lacked traits of immersive realism, and the mainstream head-mounted VR systems, where the users are isolated from the real world, enabled exploitation of collaboration in life-size virtual environments. Most practices of such collaborative virtual environments (CVEs) involved an interactive physical environment where participants could communicate and interact with each other, and with virtual characters (avatars). Some examples of CVEs, used mainly as videoconferencing systems between distributed participants, were implemented by British Telecom (BT) Laboratories in cooperation with other companies and institutes (Traill, Bowshill, & Lawrence, 1997). As the authors predicted, VEs could have a significant impact on education and entertainment by immersing—in an informative and entertaining manner—a class of students in places and events of the past or the future, and by offering the interaction essential to effective learning. Such cases of CVEs, where the emphasis is placed on learning, are reviewed further on the VE-related Section 2.5.1.

2.3.3 Section Summary

Collaborative learning has been scrutinized as a means of meaning negotiation and knowledge construction, taking place in a social world rather than in individual minds. The distinction between collaborative learning and cooperative work provided by Roschelle and Teasley (Roschelle & Teasley, 1995) has been initially adopted and we decided that the former is a better match to the simultaneous problem-solving efforts of the student groups used in this research. Through a review of theoretical approaches on collaborative learning, we concluded that the shared cognition approach can more suitably satisfy the learning needs of our audience
2.3 Collaborative Learning

collaboration paradigm, which we aspire to be reinforced by aptly designed interactions between group/audience members.

The survey of CSCL research that followed provided some insight on the ways that collaborative learning has been exploited in classrooms, laboratories, and public spaces. Also, various findings from these studies constitute a justifying force for many of our hypotheses. More specifically: a) enhancing the sense of belonging to a community for an audience will leverage their learning capacity; b) furnishing the content with collaborative activities will intrinsically motivate children to participate in social interactions; and c) providing individual control to audience members over the flow of actions will enhance their sense of engagement and active participation. A final conclusion of this survey is that there are no studies which examine how learning and overall experience are affected by the collaboration of collocated groups (i.e., more than two participants) or audiences partaking in group interactions within virtual environments.

2.4 Serious Games

Although the term “serious games” has been around for many years\textsuperscript{20}, it was only at the beginning of the new millennium that it was introduced as a novel approach for teaching serious subjects in an entertaining manner. The term became widely popular with the establishment of the Serious Games Initiative\textsuperscript{21} in 2002, having as their main goal to “help usher in a new series of policy education, exploration, and management tools utilizing state of the art computer game designs, technologies, and development skills.” Since then the term came to include the use of computer games in training for business, military, health, education, management, and advertising application domains. What is important for this research, and will be reviewed further in the next paragraphs, are serious games for education, as they came to replace the obsolete term \textit{edutainment} (a combination of education and entertainment), popularized until the late 1990s. Although serious games are being used distinctively by researchers, the term seems to overlap with other educational uses of games, such as “games for learning” and “game-based learning” (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). We are going to use these three terms interchangeably.

\textsuperscript{20} In 1970, Clark Abt's book “Serious Games” was published, triggering a breakthrough in how games and simulations can train decision makers in industry, government, education, and personal relations. Retrieved from: http://www.abtassociates.com/About-Us/50th-Anniversary/Presidents/Clark-C--Abt.aspx [last accessed: Oct 2014]
\textsuperscript{21} More information at: http://www.seriousgames.org/ [last accessed: November 2014]
thereafter to state exactly the same thing, implying the adjective “educational” when referring to serious games.

Another distinction pertinent to this research is the one between games and simulations. Games and simulations use both rules and strategies that guide the evolution of the scenario, but simulations usually represent some real-world system with low cost of error for the participants, while games are usually fantastic and the outcome is consequentially constrained within the game world (Garris, Ahlers, & Driskell, 2002). Distinction of games and simulations has also been given in terms of linearity or non-linearity of goals; a game has a finite goal which interrupts the game once achieved (e.g., when you win or lose), while a simulation has a non-linear goal structure as it supports repetitive exploration of cause-effect relationships (Gredler, 1996). A simulation game encompasses characteristics from both worlds\(^\text{22}\) and this is the type of learning game we are going to use in this research (more information in Chapter 4).

In the following paragraphs we are going to present some theoretical perspectives that indicate games as appropriate vehicles for learning, as they have been captured in the relevant literature. We continue with the most significant affective measures used for the assessment of collaborative games, especially for younger audiences such as the ones used in our research. We conclude with some studies assessing (collaborative) games as appropriate methods of knowledge dissemination. Counterarguments about the effectiveness of games as instructional tools are also presented and critiqued in the light of the goals of the current research.

### 2.4.1 Educational Promises

There has been quite some interest during the last three decades in bringing the benefits of games and their entertainment value into the education arena. Initially, computer games have been assumed to be appropriate tools for instruction by dint of increasing motivation to participate in fun learning activities and enhancing cognitive and affective outcomes (T.W. Malone, 1981). Many other researchers have been working since then towards this direction with the objective of exploiting the pedagogical benefits of gaming technologies both in formal and informal learning spaces (Barab, Gresalfi, & Arici, 2009; Gee, 2003; Prensky, 2001a; Squire & Jenkins, 2003). The more recent serious games initiative is guided towards this direction as well, with the intention to

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\(^{22}\) For an elaborate list of these characteristics see (O’Neil et al., 2005, p. 461)
motivate learners by actively engaging them in the learning process, and in most cases it is directed to domains outside of formal education (Ulicsak, 2010).

At the same time, researchers and educators were starting to value the power of commercially available video games and simulations for facilitating learning in school aged children (de Aguilera & Mendiz, 2003; Kirriemuir & McFarlane, 2004; Squire, 2005). The basic motivation for this movement was the realization that existing instructional approaches were outdated and ineffective for the students of the digital age. In other words, as Prensky (Prensky, 2001b) eloquently argued, the biggest problem of education today is the gap between the “digital natives” (learners) and the “digital immigrants” (educators). Exploiting the motivational power of games, stemming from the familiarity of contemporary children with technology, is seen as the only viable avenue of educating the current and future generations. Indeed, video games are “an integral part of their social and cultural lives” and children playing together “often evaluate their status in a peer group based on their interaction in games” (Rieber, 1996).

One of the pioneers of using games for teaching children complex concepts is Seymour Papert, who introduced the idea of microworlds with the introduction of the LOGO programming language and the robot turtles (Papert, 1980a). Microworlds allow experimentation and close study of a domain by “living” inside the domain, similarly to simulations but with two main distinctions: the learner starts with a simplified environment of incremental complexity while also matching the learner’s mental and affective state (Rieber, 1996). The main premise of Papert’s work (called constructionism; see Section 2.1.1.2) was Piaget’s constructivism, where learning is achieved through a process of self-regulation of the child’s own learning in the microworld. Knowledge construction happens through the resolution of conflict arising either by verifying existing mental models (schemes) of the problems presented in the microworld (assimilation) or building new schemes by refining and blending existing ones (accommodation) (Piaget, 1973).

More recently, the movement of serious games employed commercial, off-the-shelf (COTS) games for learning and has many proponents until now, with the single most important factor being their power to motivate learners. Such games tend to be extrinsically motivating, i.e., the rewards are exogenous to the game’s objective; an example being learning about mental rotations while playing Tetris. The goal of the game is to stack irregularly shaped bricks and finish levels of increasing difficulty, but as a consequence you hone your ability to mentally rotate 2D
shapes through repeated practice. Different genres of games are attributed with cultivating different skills. Adventure games, for example, were found appropriate for practicing problem-solving, logic, visualization, and memory among undergraduate students (Amory, Naicker, Vincent, & Adams, 1999). In a review of existing literature, de Auguilera & Mendiz (2003) reported that video games have been shown to improve spatial perception, separation of visual attention, inductive logic, iconic code construction, and cognitive development in scientific/technical aspects, among other skills. Moreover, James Paul Gee (2003) asserts that well designed video games offer thirty-six learning principles, among which are providing information contextually and on demand, enabling the formation of useful generalizations through incremental problem-solving, sustaining challenge at the growing edge of a player’s competence, and facilitating the adaptation and transformation of earlier learning.

However, using leisure games (COTS) instead of specially designed educational games has been recognized as one of the culprits of the instructional ineffectiveness of games (de Freitas, 2006). Indeed, matching the game and learning goals, which can be more easily achieved with custom learning games, is believed to be a facilitating factor in the face of challenges (Dweck & Leggett, 1988). Other inhibitors of effective learning outcomes of games, according to de Freitas, are lack of correlation between virtual and real world, inhibiting learners’ to make direct connections, and false learner expectations arising from associating game play with fun in informal contexts. The former point indicates the importance of exposing learners to authentic activities as suggested by situated cognition (J. S. Brown et al., 1989), while the latter point indicates why serious games can lend themselves aptly for learning in informal learning environments. All three points (discussed further below) seem to lend themselves better in a free-choice learning setting, as proposed by this research, as opposed to the formal type of instruction happening in classrooms.

2.4.1.1 Motivational elements of Serious Games

As mentioned above, besides being inherently fun, games can be intrinsically motivating; i.e., if the goal of the game is the same as the learning objective. Significant factors of a game with endogenous rewards that can facilitate intrinsically motivating learning, as defined by Malone and Lepper (1987), are fantasy, curiosity, challenge, and control. Fantasy is defined as an environment that evokes “mental images of physical or social situations that do not exist” (p. 240) and is claimed to have both cognitive and affective advantages in instructional design. Cognitive curiosity can be
beneficial if stimulated by making learners believe their cognitive models are incomplete, inconsistent, or unparsimonious. Optimal levels of challenge enable learners to go through the learning activities without feeling anxiety from unsurmountable difficulty or boredom due to overqualification—more about the balance of challenge and abilities is discussed in (J. Chen, 2007) and under Section 2.4.2. Finally, control is related to the degree of agency the learner can exert in the game (similar to the level of interactivity researched in this work), and has been shown to affect motivation and learning outcomes in school children (Cordova & Lepper, 1996).

Garris et al. (2002) suggest that there are six key dimensions of games that need to be harnessed in order to achieve the desired instructional goals: fantasy, challenge, control, mystery, sensory stimuli, and rules/goals. The first four overlap with Malone & Lepper’s factors of intrinsic motivation, with mystery replacing curiosity as a property of the game itself and not a learner-dependent construct. Sensory stimuli implies “the temporary acceptance of another type of reality” (p.469) and is achieved through dynamic graphics and sound effects—the term is related to presence in virtual environment and will be reviewed further in Section 2.5.1. Clear and specific game rules increase motivation by making learners more attentive to goal-feedback discrepancies, and eventually increasing performance. Finally, the authors postulate that games themselves are not sufficient vehicles for learning; rather it is specific game elements that can be activated within an instructional context that can facilitate the learning process.

The aforementioned are just two out of the numerous taxonomies that link motivational elements of serious games to learning. In an attempt to come up with a consistent categorization of game attributes and their connection with learning outcomes, Bedwell, Pavlas, Heyne, Lazzara, & Salas (2012) conducted a comprehensive literature review and subsequent card sort session with game experts. From their extensive survey of existing work (summarized on pages 747-52), they came up with nine game attributes that they consider can adequately describe a wide range of potential game states and features that predict learning: action language, assessment, conflict/challenge, control, rules/goals, environment, game fiction, immersion, and human interaction. Although the authors recognize the difficulty of manipulating these constructs independently, they still suggest that this is a useful taxonomy for experimentally evaluating the game attribute-learning outcome relationship efficiently, in game-based learning research.
2.4.1.2 Simulations as authentic learning environments

As discussed before, the main premise of situated cognition is that students learn best if they are presented with authentic activities within the context of the subject matter. This is achieved through a process called cognitive apprenticeship, which can be achieved if: a) task processes are transparent to students; b) abstract learning tasks are situated in authentic contexts that make sense to students; and c) learning tasks are presented in an incrementally diverse form to aid generalization of skills and transfer of knowledge (Collins, Brown, & Holum, 1991). Although the authors suggested how teachers can accommodate these guidelines to simulate traditional apprenticeship in the classroom, simulation games have the potential to satisfy all three requirements presented above by design. Indeed, learners using simulations have been shown to better understand the relationship of the content with real-life experiences upon reflection, since the simulation is closely connected with the learning context (de Freitas, 2006).

Furthermore, play involves a child’s attempt to inhabit a simulated imaginary world in order to satisfy some desire which cannot be immediately gratified (Vygotsky, 1978). Similarly, according to Shaffer (Shaffer, 2005) epistemic play involves the immersion in an authentic simulation that provides learners “access to the epistemic frame of a community of practice” (p.2). Simulation games, or epistemic games as he calls them, can be effective due their profound potential to educate students through their active participation in “authentic recreations of valued reflective practices.” Even more, in the case of collaborative simulation games, assuming different roles and level of participation according to expertise (e.g., in the domain or game playing) is similar to how an apprentice takes over more complex tasks as she becomes more skilled (Lave & Wenger, 1991). Within that context learning is a cooperative process in which all participants develop their skills through their actions and relations with other agents within the (game) world.

2.4.1.3 Game-based learning in informal contexts

Due to their entertaining character, serious games have been also used outside of formal education, to cultivate not only cognitive but also soft skills (e.g., communication, interpersonal skills, creativity, empathy, etc.), in both school and university students (Koo & Seider, 2010; Pivec & Dziabenko, 2004). Research efforts like these usually involve some degree of collaboration, which is either asynchronous happening through online environments, or—less often—occurring synchronously with students collocated in the same setting. The former scenario usually involves
some kind of multi-user game, such as a commercial or custom multi-user virtual environment (MUVE) or a massively multiuser online game (MMOG), both of which are going to be briefly discussed for their educational value in Section 2.5.1 on virtual environments. The latter has received much less attention in research and the few instances we are aware of are applications in museums and science centers, where games are mainly used as a motivating factor to engage visitors more deeply with the exhibits; e.g., through scavenger hunt games using mobile devices (Klopfer et al., 2005; Yiannoutsou & Papadimitriou, 2009). Our research aims to partly fill this gap of assessing collocated collaborative game-based learning in museum spaces.

What makes these places unique for game-based learning are the affordances they offer for simultaneous collaboration of a larger audience of learners. Collocated collaboration among participants in interactive experiences in such spaces can be used both as a means to facilitate learning through communication of intentions, negotiation of actions, and reflection of outcomes, as well as a motivating factor by itself (i.e., arising from the increased opportunities for social interaction). Moreover, socio-physical dynamics of digital games are believed to be a significant contributor to game experience and its (learning) outcomes (De Kort & Ijsselsteijn, 2008). It is important to make the distinction here between Vygotsky’s view of learning as the internalization processes occurring through the transformation of social phenomena (e.g., social interactions during game play) into psychological phenomena, and Piaget’s constructivist view of internalization as a result of self-regulation during children’s interactions with the physical world and the manipulation of objects (Wertsch, 1985). As stated by Wertsch, these approaches are complimentary rather than mutually exclusive, and their implications on how children learn in the complex environment of collocated collaborative play with digital games are significant and pivotal to this research.

Finally, introducing social gaming inside the museum space seems like a good match as far as common expectations are concerned, in regards to the entertaining character of both the museum visit and gaming experiences. Fulfilling the expectations of museum visitors seems to have a beneficial effect on learning, especially for intrinsically motivating visitors building social bonds and shared knowledge (John H. Falk & Dierking, 2000), similar to how intrinsically motivating instruction can facilitate learning using computer games (T.W. Malone, 1981). However, making the (gaming or museum) experience overly fun might have adverse effects, as learning outcomes seem to be affected by the learners’ attitude and expectations, or their “leading
motive orientation” (Hedegaard & Fleer, 2013). The culturally and contextually dependent motive orientation (i.e., play or learn) can affect the learning outcome, thus playful experiences need to provide a thoughtful balance between fun and actual instruction.

2.4.2 Assessing Affective Measures in Games

The primary goal of a game is to entertain, and as such it influences the players’ affective states, which include the psycho-physiological constructs of valence, arousal, and motivational intensity. Affect is one of the three main divisions of the mind according to modern psychology: the cognitive, the conative (guiding behavior), and the affective. The function of affect in games is mainly to guide attention and decision making, while it is also a formulating factor of social behavior during our interactions with others (Damásio, 1994). In most cases, especially outside of the classroom, children play games in order to experience an imaginary world (role play) that can satisfy their emotions, desires, and impulses and effective instruction should take this into account in every stage of childhood (Bodrova & Leong, 2006).

Thus, besides the cognitive benefits of serious games, it is important to also consider the fundamental question of “why people play games?” which stems from the player’s affective and conative (impulsive) states during game play. Lazzaro (2004) attempted to respond to this question by observing thirty adult gamers and came up with four key motivational elements: a) hard fun, which includes experiencing challenges, thinking strategically, and solving problems; b) soft fun, which involves eliciting wonder, awe, mystery, curiosity, and intrigue; c) altered states, where players indulge in the relief and excitement of changing their—negative—internal emotional state; and d) the people factor, where motivation arises from the need for social bonding, team play, personal recognition, and competition.

Others have tried to come up with a model or framework for either guiding the design of games or aiding in their evaluation. As an example, the GameFlow model suggests that there are eight main elements of flow (explained further below) that can effectively predict enjoyment with games: concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction (Sweetser & Wyeth, 2005). Although the model was evaluated with expert reviews of two real-time strategy games, the authors suggest that it is an appropriate model for describing enjoyment in a wider genre of games. The Pervasive GameFlow model (PGF) augmented the initial list with fourteen more enjoyment criteria in an attempt to capture the most significant elements of
crossmedia (i.e., happening across different media, such as mobiles and the web) pervasive games (Jegers, 2009). The author concludes that the three most significant measures for assessing fun in pervasive games are immersion, challenge, and concentration.

Similar research efforts have revealed a variety of player enjoyment measures, the most significant of which are presented briefly below. In most cases these measures have not been investigated in terms of their effects on learning with serious games, which is one of the main goals of our research. In order to best juxtapose these affective measures of games with the Contextual Model of Learning happening in museums (presented in Section 2.1.3.2), we present them in two different contexts: game experience, which best describes leading emotions in the personal context, and social presence, which encompasses the emotions attributed to the players copresence within the social context. We also include a description of the assessment instruments we decided to use in our research and a rationale for their selection.

### 2.4.2.1 Game Experience

Game experience is an overarching concept embracing a sum of gaming constructs that contribute to game enjoyment and the overall gaming experience. The way we use it in our research, it refers to the subjective experiences of the individual while playing computer games, and does not include measures of collaborative game play (these are mentioned in the next section). First, we briefly review the main constructs that are most often used to characterize game experience by the majority of the relevant literature. Then we present the main research efforts for measuring game enjoyment, which were developed for evaluating or guiding the design of commercial video games, including the one used in our research.

**Immersion** in the story refers to the degree the player feels as being part of the game narrative and higher levels lead to a stronger sense of being an actor inside the game. Immersion is tightly linked to engagement and should not be confused with attributes of the display technology (more under Section 2.5.1). In some cases immersion is distinguished between imaginative—related to the game story—and sensory—caused by the graphic and audio game elements (Poels, de Kort, & Ijsselsteijn, 2012). Additionally, some distinction has been made between the pleasure that arises from immersion—stemming from our ability to actively influence the interactive story—and engagement—stemming from the sense making process of the game’s challenges by resolving incongruences (Douglas & Hargadon, 2001).
**Presence** is widely defined as the feeling of “being” inside a virtual world and is most commonly used in the field of Virtual Reality (as such we will review it further in the respective Section 2.5.1.2). A difference suggested between presence and immersion is that with the latter the player still retains some awareness of the surroundings, while during the former she is totally immersed within the virtual world (Baños et al., 2004). We should clarify that immersion is used here as a psychological construct (see above) and not as a property of the technology.

**Flow** refers to the intense feeling of enjoyment that is experienced by being fully engaged with some kind of activity, such as sports or playing music (Csikszentmihalyi, 1990). Flow is used to describe an optimal state of performance in a task or activity, and is characterized by full absorption in a task with clear goals and consistent feedback, where the individual’s abilities match the task’s challenge level, and where the individual experiences a high sense of control causing suspension of self-consciousness and distortion of time. Such properties have been observed in game playing especially when there is a match between skills and demands (Keller & Bless, 2008), which drove researchers to use flow in many models predicting digital game experiences (Jegers, 2009; Sweetser & Wyeth, 2005). Moreover, learning is believed to be most effective if it is self-motivating, emotionally satisfying, very personally rewarding, and challenges involved do not exceed the learner's skills; all of which are properties of flow and can be easily facilitated in museum spaces (Csikszentmihalyi & Hermanson, 1999).

**Challenge** has also been related to game experience by means of enabling or inhibiting the progression of the game, eventually affecting enjoyment. Challenge should optimally match the abilities of the players, according to flow theory; if game challenges exceed the skills of the player then frustration and anxiety arises, while if the player’s abilities are far beyond the challenge level then boredom and loss of interest occurs (J. Chen, 2007). As such, challenge can induce various feelings related to both positive and negative affect such as thrill, hope, suspense, anxiety, tension, and pressure (Poels, de Kort, et al., 2012). Suspense, a construct closely related to challenge having to do with the player’s sense of uncertainty and the expectations of negative outcomes, has also been found to predict game enjoyment; more specifically, creating suspense over longer periods of time contributes to sustaining game enjoyment (Klimmt, Rizzo, Vorderer, Koch, & Fischer, 2009).
**Competence** is inversely correlated with challenge and includes positive feelings such as self-efficacy, pride, accomplishment, and content. As discussed above, competence is inherently dependent on the difficulty of the challenges imposed by the game mechanics, but also by the task of controlling the game. As a consequence, if either of the two exceeds the capacity of the player then negative feelings (e.g., anxiety, frustration, anger) are produced and game enjoyment is decreased. On the other hand, intentionally fluctuating the difficulty level in games helps gamers gradually evolve from negative emotions in the face of increased challenges to positive emotions (e.g., flow), when eventually player competence can match the challenges being faced (Ravaja et al., 2004).

**Control** usually refers to a game property attributed to interactivity, but in some cases it has been used as the perceived degree of agency in the game (similar to perceived interactivity discussed in Section 2.2.2). Increased level of control provides a sense of autonomy, power, and freedom to explore and experiment with the game, which has been shown to contribute to improved game experience (Poels, de Kort, et al., 2012). Also, **effectance** is a precondition of control and is experienced when players receive immediate feedback in their attempt to influence the game world (Klimmt, Hartmann, & Frey, 2007). In their study with an online game using different levels of control and effectance, the authors concluded that effectance significantly affects game enjoyment, but control does not have a linear relationship, as it affects other contributing factors of enjoyment, such as challenge and suspense, and thus is hard to directly assess its impact.

We have come across two concise game experience instruments during our investigation. First, the Game Engagement Questionnaire is an instrument for predicting psychometrically the levels of engagement of game players while playing video games, and was mainly developed as a tool for examining the risk of adverse effects of violent video games (Brockmyer et al., 2009). The questionnaire includes nineteen questions and the authors believe that it can adequately measure engagement using the affective constructs of **flow**, **presence**, **immersion**, and **psychological absorption**. Second, the Game Experience Questionnaire (GEQ) was developed by the Game Experience Research Lab at the Eindhoven University of Technology in an attempt to move computer game evaluation away from the traditional usability measures of user-centered design, taking into account behavioral and psycho-physiological measures (Ijsselsteijn, Kort, Bellotti, & Jurgelionis, 2007). The questionnaire includes three different modules (core, in-game, and post-game) and is broken down into seven different dimensions that contribute, positively or negatively,
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to the overall game experience: immersion, flow, challenge, competence, positive affect, negative affect, and tension.

There is a different motivation between the two instruments, with the former aiming at identifying the game elements that lead individuals to be engaged in violent video game playing, while the latter was designed as an assessment tool for the subjective experience of playing computer/video games. Thus, we found the GEQ a more appropriate self-report instrument for measuring game experience, as it was more sensitive to a broader range of emotions associated with digital game experiences and potentially affecting learning, also providing a version specifically for kids. Although not specifically designed for learning games, we believe this multi-measure approach can capture the different affective states that a game player experiences in a serious game.

2.4.2.2 Social Presence

The main attribute affected by collocated collaboration is social presence, which is the sense of awareness of being together with an interacting partner, and was initially used during telecommunication studies (Short, Williams, & Christie, 1976). Studies have shown that playing together with or against others while in the same space yields greater enjoyment, challenge, and perceived competence (Gajadhar, Kort, & Ijsselsteijn, 2008). Another study indicated that access to nonverbal cues through video communication while in a networked CVE did not result in increased social presence as compared to just audio, which in part was attributed to the use of avatars as a means to express indirect cues such interpersonal proximity, gaze direction, etc. (Sallnas, 2005). Furthermore, the mere collocation of collaborators does not always imply greater social presence, since other factors such as physical environment and application design affect communication (de Kort & Ijsselsteijn, 2007).

Additionally, the nature of the players’ relationship with each other has been shown to impact the sense of social/spatial presence, engagement, and physiological arousal in video games positively, with greater acquaintance revealing greater gains (Ravaja et al., 2006). Although not directly assessing social presence, comraderie and cohesion deriving from collaboration among friends has been shown to improve performance by facilitating social conversation and task completion in both decision-making and motor tasks (Shah & Jehn, 2001). On the other hand, friendship might also have a detrimental impact on performance during collocated collaboration.
by dint of being slack with responsibilities as opposed to working diligently in order to establish a good reputation (Maldonado, Klemmer, & Pea, 2003).

Considering these contradicting results of prior work, it would be interesting to investigate the effects of the—more often than not—positive influence of social presence on learning games. Before we do this, we will first present the main constructs of social presence that are believed to affect player enjoyment and overall game experience. We will then present the main available instruments for measuring social presence and provide our rationale for the one selected for this research.

Empathy concerns our ability to recognize and identify with the emotions of another sentient or fictional being, and has many implications in games both in terms of virtual character (avatar) design (Lankoski, 2007) but also for designing collaborative game play. Our main concern in this research is the latter, as it is believed that social and affective aspects (such as empathy) of learning communities should be seriously considered in designing appropriate computer mediated technology that can support the development of socio-emotional skills, especially in children (Jones & Issroff, 2005). Games offer also the opportunity to interact and explore the game environment in the company of others, and as a consequence cultivate empathic and prosocial skills in players (Koo & Seider, 2010). Empathy is a major part of what has been broadly called psychological involvement in social presence theories (Biocca, Harms, & Burgoon, 2003; de Kort & Ijsselsteijn, 2007; Short et al., 1976), which might also involve negative feelings in the form of jealousy, revenge, envy, and indifference.

Behavioral engagement or interconnectedness is the degree to which the collaborators, or game players, feel interdependent. Behavioral involvement is apparent mostly in virtual environments where real or synthetic characters react to the players’ actions, increasing the sense of being inside the virtual world with others (Heeter, 1992). Also, as has been identified by Palmer during the early days of VR, social presence involves the effective negotiation of “a relationship through an interdependent, multi-channel exchange of behaviors” (Palmer, 1995, p. 291). Hence, it is through the behavioral interaction and synchronization with the actions of others that social presence might become more salient (Biocca et al., 2003), and evaluating the impact of the socio-physical dynamics of collocated gameplay on the players’ behavioral involvement is expected to
influence the digital game experience (De Kort & Ijsselsteijn, 2008) and potentially the learning outcomes.

**Competition** is considered another motivating factor in playing video/computer games. Although competition may refer to drawing satisfaction by mastering the game while playing against digital opponents, we mainly refer to social competition here where players compete with each other. A study about the effects of competition on player enjoyment weakly supported the fact that players with a predisposition to compete enjoyed competitive games the most and experienced higher levels of self-efficacy (Vorderer, Hartmann, & Klimmt, 2003). Moreover, another study comparing playing against a computer or human opponent, revealed greater spatial presence, engagement, physiological arousal, and positive valence for the latter condition (Ravaja et al., 2006). In education, competition has been both praised and criticized as compared to cooperative and individualistic efforts in terms of the learners’ performance (D. W. Johnson & Johnson, 2009); however our research concerns only collaboration using learning games.

There have been quite a few instruments devised over the years for measuring social presence, the most popular of which are the Semantic Differentials used initially by Short et al. (1976), the Networked Minds questionnaire (Biocca, Harms, & Gregg, 2001), and the Social Presence in Gaming Questionnaire (de Kort & Ijsselsteijn, 2007). The first two instruments were basically developed and evaluated for use in communication through teleconferencing systems. The Semantic Differentials is a method for assessing people’s attitudes by measuring directionality of a reaction against two contrasting adjectives (e.g., personal vs impersonal), and has been used by Short et al. to characterize the medium instead of the participants’ feelings, which is one of its main weaknesses (Gooch & Watts, 2011). The Networked Minds tool uses forty questions related to eight factors considered to contribute to social presence: *isolation/inclusion, mutual awareness, mutual attention, empathy, mutual understanding, behavioral interaction, mutual assistance*, and *dependent action*. These factors are distributed along the following three theoretical dimensions in incremental order of eliciting social presence: co-presence, psychological involvement, and behavioral engagement. This tool has been reported to be accurate by means of capturing the increased social presence felt by people collaborating face-to-face as compared to working through teleconferencing.
2.4 Serious Games

The final questionnaire (SPGQ) is complementary to the GEQ presented above and is used to capture the effect of the social context and interactions on the digital game experience. The SPGQ was based on the Networked Minds questionnaire and comprises twenty-one questions which are measuring three distinct constructs: empathy and negative feelings as part of the players’ psychological involvement and behavioral engagement capturing the interdependence of players, which is significant in game experiences. We chose the SPGQ for our research because of its appropriateness for evaluating social presence in gaming settings. This distinction arises from the continuous player interdependence noticed in gaming VEs demanding teamwork, which is not usually the case in teleconferencing systems (de Kort & Ijsselsteijn, 2007). The three constructs of the SPGQ were considered appropriate for the collocated nature of the game, plus it also includes a version for child gamers.

2.4.3 Game-Based Learning Research

There is an abundance of research about games used for education purposes over the last four decades, especially after Papert’s robot turtles (Papert, 1980b) and Malone’s theory of motivating learning through fun (Malone, 1981). However, the types of games that have been used span across a wide range of genres, used for different types of learning, within different contexts, making it infeasible to review all of them here. Thus, we will focus on specific kinds of games, which match most of our research’s requirements (i.e., simulation games, cultural heritage games, multi-user games, and games for museums), either individually or by combining more than one requirement. We also need to mention that many serious games employ virtual worlds, which are mainly reviewed under Section 2.5.2, but will still be included here if they are building on their gaming properties to facilitate learning. Finally, we will present some critical views about the efficacy of discovery learning and serious games, taking a position about the reason we chose to walk down this path for this research.

Early initiatives to explore the educational benefit of games involved the use of commercial games in classrooms, as a means to make traditional instruction more compelling to students. One such study utilizing the game Civilization III revealed that low-achieving students found the game more appealing and benefited the most in learning about history and politics, as compared with students who perform generally well in class who were reluctant in accepting the game as a legitimate learning tool (Squire, 2005). Other empirical studies found experiential learning with
video games to be potentially beneficial, but only when the game’s goals and the learning objectives are closely linked (Egenfeldt-Nielsen, 2005).

However, using commercial games instead of specially designed educational games and false learner expectations arising from associating game-play with fun have been identified as two of the main inhibitors of effective learning outcomes when using games (de Freitas, 2006). The first point motivated some researchers to combine appropriately designed learning modules and embed them in custom-made, high-end computer games, in order to enhance the educational value of video games. In such an effort, Bellotti et al. (2009) developed SeaGame, a custom virtual world based on state-of-the-art commercial game-engine technologies enriched with educational mini-games, and found that the game was perceived equally enjoyable and engaging to available commercial games by high school students experienced in video games. However, no evaluation of the learning outcomes of the game was reported in this work.

The second point made by de Freitas indicates why serious games might lend themselves aptly for learning in informal contexts, as compared to classrooms, where expectations about the nature of the visit match these of the game environment. Games in museums have been mainly used in order to more effectively engage visitors with the museum exhibits. As an example, Klopfer et al. (2005) employed an interactive game called Mystery at the Museum as a means to facilitate collaboration among parents and their children (mostly middle school students), in order to deeply engage them with various exhibits across the museum space. Qualitative results showed that role assignment to individual players promoted collaboration and fostered their sense of unique contribution to the assignments; however, learning gains caused by the collaborative nature of the game were not reported. Moreover, the book Museums at Play: Games, Interaction, and Learning contains an impressive collection of work encompassing the application of games as a means to elicit and nurture curiosity, challenge, cooperation, choice, creativity, and discovery in museum visitors, in museums across fourteen countries (Beale, 2011). Once more, the effect of game experience and social presence (when collaboration is supported) on learning has not been formally assessed in any of the included work.

Collaboration has been mainly studied in the context of online or Internet games, mainly within a classroom. In such a study Garzotto (2007) tested a 3D interactive game for teaching about cultural diversity to elementary students, through an online game called Pirates, which
involved two remotely located competing teams. The teams consisted of 2-3 players each and had to work together on a desktop computer, trying to complete the game before their opponents. Using a pre/post-test design they found significant learning gains after the intervention, as well as increased enjoyment (deriving mainly from the discovery type of learning), immersion, challenge, and competition (associated with increased cooperation among group members). However, within-group interaction was the least compelling attribute of the game, with conflicts about game control emerging in most groups. Our research is motivated by efforts like this, where the benefits of simultaneous interaction within groups are largely unexplored.

Multi-user serious games have been used with a variety of learning applications, such as for disseminating cultural heritage and scientific inquiry. The work of Bellotti et al. (2012) is just one case where a multi-user, sandbox-style serious game was used for a cultural heritage application, employing a task-based learning approach by breaking down knowledge constructs in mini-games. The user studies involved the assessment of knowledge acquisition (i.e., learning about the artistic activity of a famous Italian painter), by domain non-experts using either the mini-games or reading an equivalent document with text and images. Results showed that learning between the two conditions, as assessed by domain experts who also built the games, was not significantly different. Moreover, mini-games were not shown to be considerably more enjoyable than reading texts, which was attributed to the inferior game design as compared to commercial video games. Besides the fact that this research included university level students working in a controlled environment, it provides no account whatsoever about the effects of collaboration, although this was described as a multiplayer game.

Maybe one of the most influential research efforts on multi-player games for learning is *Quest Atlantis*, a MMOG (supporting more than 55K players) used for positioning students as active actors in solving real-world problems while experiencing the consequences of their actions (Barab et al., 2010). This research leverages the benefits of both virtual environments (see Section 2.5) and simulation games, by engaging learners in authentic experiences. In one of their studies, the researchers compared learning outcomes (using pre/post-test questionnaires) and engagement (using the flow survey) between a game-based and story-based lesson on persuasive writing (Barab, Pettyjohn, Gresalfi, Volk, & Solomou, 2012). The game-based platform revealed significantly greater learning gains and engagement levels, with most students (ages 9-15) reporting intrinsic motivation as opposed to external rewards (i.e., grade or teacher instruction),
which was the major motivation for the story-based participants. Although this is a promising work about the usefulness of serious games, it does not involve collocated collaboration, while also the learning context (curriculum-based education) is different than our own research.

Very few examples exist comparing cultural heritage games across platforms and contexts. In such a research Chen et al. (2011) investigated the effects of platform setup (lab, online, museum) and order of subsystems with different levels of immersion (engagement, engrossment, and total immersion—only for the online setup) on learning outcomes and entertainment level with a serious heritage game. The system employed 3D avatar personalization and gesture-based interaction in order to increase immersion and was mainly tested with high school students (ages 14-21). No significant differences between conditions are reported, besides an increase of entertainment level for the museum (large screen) condition. However, the experimental design was questionable (e.g., why was degree of immersion varied only in the online platform?) and the learning measures were too simplistic to be credible (i.e., only one very simple question/task per subsystem was used).

Admittedly, our literature review on empirical studies in game-based learning did not reveal many results supporting the effectiveness of serious games over other types of instruction. There is a limited amount of such evidence (e.g., Barab et al., 2012; Garzotto, 2007), which however, in most cases fall under the highly-debatable area of media comparison studies (Warnick & Burbules, 2007). As a result, many scholars have argued against the soundness of such evidence (Clark, 2007; Gredler, 1996; O’Neil, Wainess, & Baker, 2005), postulating that serious games cannot deliver anything more than factual knowledge, which cannot be taught equally or more effectively with traditional instruction; in many cases, even questioning the motivational superiority of game-based approaches. Criticisms include inconsistent distinction between serious games and simulations, lack of direct measures of learning and/or motivation, unequal comparison of conditions, and failure to account for prior knowledge of participants. Moreover, simulation games have been shown to be more effective only when they are mixed with other instructional approaches and comparative conditions of traditional instruction do not involve learners actively (Sitzmann, 2011).

A parallel line of arguments includes the ineffectiveness of unguided discovery learning, which is largely where serious games usually fall. Considering that such games are mainly used
for constructivist learning, where learners are in charge of their own learning through exploration and self-regulation, the degree of guidance needed in constructivist settings has been the field of quite some controversy. More specifically, proponents of more traditional methods of instruction (and obviously of the cognitive information processing approach to learning—see Section 2.1.1.2) are postulating that minimal guidance during an instructional activity is not enough to facilitate the cognitive processing necessary for learning (Kirschner et al., 2006). Similarly, Mayer (2004), based on a meta-analysis of research on discovery learning practices over the last five decades, argues that there is accumulating evidence that unguided instruction during discovery learning often proves to be less effective as compared to guided instruction.

Considering the aforementioned arguments against serious games and unguided instruction, one of the goals of this research is to shed light on the educational benefit of using these technologies in a new context and for a different audience. More specifically, we believe that the museum space lends itself aptly to a game-based learning approach, where a large number of students/visitors are called to get something meaningful out of a limited duration interaction. The option for a traditional instructional approach does not exist and even if it did, it would have defied one of the major objectives of a museum visit, i.e., to entertain. The current best practice involves museum educators/curators providing a presentation of digital exhibits or games, where maintaining the interest and engagement of a large group is very challenging. Thus, one of the main goals of this research is to test the feasibility and effectiveness of engaging and informing a group of student-visitors of a museum in an entertaining way (with or without facilitation), trying—in part—to fill the identified gap in research of “determining the return on investment and outcomes from game-based [learning] approaches” (Sawyer, 2005).

2.4.4 Section Summary

Serious games include many different genres of games with a serious intent such as teaching/informing about health, business, and education. Our focus in this work is serious games for learning, also referred to as learning games or game-based learning. We initially reviewed the most commonly documented promises of game-based learning research and especially of simulation games, which is the type of game used in our research. We then elaborated on three of the main benefits that games can bear in education: increasing learners’ motivation (and the main elements
for achieving that), involving students in authentic experiences, and leveraging their entertaining nature for informal learning.

Affect has been shown to play a decisive role both in entertaining experiences, such as game playing, but also during learning. Thus, we reviewed the most important affective measures in games, exploring the constructs that have been identified as contributing the most to elevated game enjoyment and engagement. We, specifically, presented these measures that are believed to improve the personal game experience (i.e., immersion, presence, flow, competence, challenge, and control), but also the measures that are shown to impact social presence in collaborative game playing (i.e., empathy, behavioral engagement, and competition). In both cases, we presented and justified the selected assessment tool in our research.

Finally, we presented some representative examples of game-based learning research, mainly the ones incorporating some of the same attributes with the simulation game we developed in the context of this dissertation work; i.e., a cultural heritage, multi-user, simulation game for use in a museum. Concluding, we presented some of the counterarguments about the effectiveness of unguided discovery learning (with serious games) and gave our rationale for deciding to employ such a game for the assessment of collaborative group/audience interaction and learning in informal education contexts.
2.5 Virtual Environments

We define a virtual environment (VE) as a computer-generated, graphical world that supports the perception of simulated 3D space, according to the description of VEs given by Sherman and Craig (2002). In most cases, this involves a user, or users, interacting with a synthetic, simulated environment using a display device (e.g., a screen or a head-mounted display) and some sort of interaction devices (e.g., a joystick, a tracked device, or their own tracked body). The environment can either be a totally fantastic or infeasible to visit 3D world (e.g., our inner body), or a realistic representation of an existing or long-gone site (e.g., an ancient city). The user has usually a first-person perspective in the virtual world, but it is not uncommon to be presented with a third-person point of view, such as looking over the shoulder of a virtual character.

VEs are based on virtual reality (VR) technology, which was initially used by the military for training purposes mainly using flight simulators—one of the first VEs that have been developed. At the time, the technology was too expensive to be useful outside the military and industrial domain. However, during the 1990s VR became more easily accessible by universities and research institutes, leading to its exploitation for educational and entertainment purposes. In education, VR has been mainly connected with the increased popularity of constructivist learning approaches (Youngblut, 1998). Merging VEs with game design to produce compelling experiences for visitors of LBEs was also suggested as an effective practice (Clarke-Wilson, 1998), with some reputable entertainment companies making the first steps in this direction, such as Disney’s Aladdin project (Pausch, Snoddy, Taylor, Watson, & Haseltine, 1996).

In the following paragraphs we review the foundations on which scholars suggested that VR and VEs are fruitful tools for imparting knowledge, presenting the technology’s most beneficial attributes for achieving this, while also reviewing the most prominent examples of educational VEs research. We try to also address the use of collaboration in VEs for enhancing learning, the use of gaming or entertaining elements for improving the user experience, and any examples of using VEs in informal learning spaces.

2.5.1 Educational Promises of VEs

As mentioned above, learning in VEs has been studied for more than two decades—since the time when virtual reality technology became accessible to research labs in the early 1990s. By that time,
researchers were arguing that learning approaches must depart from objectivism (i.e., knowledge existing independent of learners’ minds) towards constructivism, where learning occurs through socially active learning environments, through the interactions of people and artifacts (Duffy & Jonassen, 1992; Jonassen, 1994; Winn, 2002). In that context, VR has been mainly used for promoting conceptual learning. More specifically, it has been suggested that promoting conceptual learning using VEs demands that students are engaged in sense-making activities instead of simply using traditional instruction methods, such as drill and practice (Whitelock, Brna, & Holland, 1996). Thus, besides the medium itself, it is the type of learning activities and their implementation that greatly define the effectiveness of educational VEs.

A more thorough look into the properties of constructivism as suggested by Jonassen (1994), reveals how VEs can aptly satisfy these requirements for learning. More specifically, constructivist learning environments should enable content and context-dependent knowledge construction, present authentic activities, use multiple representations of reality, and also support collaborative construction of knowledge through social negotiations. VEs can nurture many of these pedagogical approaches suggested by the constructivist philosophy, by having students uncover critical concepts through experimentation (guided-inquiry), or having them learn within the actual context where learning is to be applied (experiential and situated learning); most importantly, learning-by-doing in a safe and cost-effective manner, circumventing the constraints imposed by traditional instruction at school (Youngblut, 1998). These benefits are similar to a great extent to the ones we reviewed under simulation games (in Section 2.4), and it only makes sense to assume that combining these two technologies can increase the learning benefit.

In a similar vein, Dalgrano and Lee (2010) suggested that the most important learning affordances of 3D VEs include greater opportunities for experiential learning, increased motivation and engagement, improved contextualization of learning, facilitation of spatial understanding, and more effective collaboration as compared to 2D learning environments. Considering that their suggestions stem from a more recent review of related work, it is important to note that they identified that there has not been enough evidence of the educational value which derives from the unique attributes of VLEs and especially their 3D aspect. Other researchers have also stressed our inadequate understanding of the cognitive benefits of desktop and immersive 3D VEs (E. A. Lee & Wong, 2008), which is one more motivating factor for pursuing this research.

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Besides the few examples mentioned above, there has been an abundance of scholarly work emphasizing and elaborating on the potential benefits of VEs for learning, and an equal number of studies that are trying to assess the validity of these arguments. In the following paragraphs, we have categorized such work in the distinctive attributes of VEs that have drawn the most attention by researchers so far, for their purported educational value. We briefly present each one of them, giving some characteristic examples of studies that attempted to assess their impact on learning.

2.5.1.1 Autonomy and Interaction

As we saw at the beginning of this section, manipulation of the VE and its containing objects demands some kind of interaction on behalf of the user. Interaction or interactivity, along with presence (discussed below) are considered the two fundamental properties of VR environments (Zeltzer, 1992). Zeltzer even distinguishes between autonomy, as the extent to which virtual objects can respond to events and stimuli by the user (human-control) and/or the environment, and interaction, as the degree of access to the parameters of virtual objects (real-time control). Others have defined interactivity in VEs as “the degree to which users of a medium can influence the form or content of the mediated environment” (Steuer, 1992, p. 11), which better matches Zelzer’s autonomy (for a more elaborate discussion on interactivity see Section 2.2).

Besides the widely suggested impact of interactivity on learning (more under Section 2.2.3), surprisingly, not many studies attempted to assess the validity of such claims in VEs. One of the first studies (Byrne, 1996) had high-school students use different systems with different degrees of interactivity (interactive and animation/video) and immersion (VR and desktop), comparing their understanding on atomic and molecular structure (using a pre/post-test). Students in the interactive conditions (either a VE using a high-resolution helmet or a desktop interactive application) scored significantly better, indicating that interactivity helped them acquire a better understanding of the material.

Perhaps the most influential work so far on VEs for learning is the ScienceSpace project where researchers assessed the impact of VR properties like multisensory immersion, multiple representations, and interaction for teaching complex and abstract scientific concepts (Dede, Salzman, & Bowen Loftin, 1996). These researchers found some attributes of the technology promising as a constructivist tool for learning science, including multimodal interaction, however interactivity in the VEs was too simplistic involving simply navigating and changing parameters,
without the ability to alter the environment dynamically through user participation. Other studies of the same period, such as the summer camps in VR by the HIT Lab (Bricken & Byrne, 1993) and the Virtual Solar System (S.A. Barab et al., 2000), focused on providing students with 3D tools for building virtual worlds in order to construct their knowledge through modelling and experimentation. Although interactivity was involved for the development of the VEs, it was not assessed for its effectiveness on the learning process.

A more recent study assessing specifically interactivity’s impact on learning inside a VE, was conducted with primary school students who had to learn about fractions by being immersed in a CAVE (Roussou, Oliver, & Slater, 2006). Students immersed in the Virtual Playground had to complete a set of tasks about arithmetic fractions, using two VR-conditions with different levels of interactivity (interactive and passive). The researchers used Activity Theory (Jonassen, 2000) to analyze the results qualitatively and found indications of interactivity aiding problem solving, but no strong evidence of conceptual change was found using pre/post-test results, with the robot-guided (passive) condition better facilitating student reflection and recall than the fully interactive condition. These findings indicate the need for more research on the effects of interactivity on learning in VEs.

### 2.5.1.2 Immersion and Presence

Immersion has been used differently in various contexts (e.g., as a property of games having to do with narrative—see Section 2.4.2) and in some cases it has been confused with presence. In this research we will distinguish between immersion as a property of the technological medium (in our case the VE), and presence as the subjective, psychological sense of ‘being’ inside the virtual world, also referred to as perceptual and psychological immersion (Biocca & Levy, 2013). Presence, or telepresence, has been heavily researched over the years (Lombard & Ditton, 2006), as it constitutes a unique characteristic of VR that makes it appropriate for training, education, and entertainment, by suspending the disbelief of residing inside a synthetic environment and experiencing the feelings of a real-world situation.

As a human experience, Steuer (1992) suggested that telepresence is affected by two technological variables: vividness, i.e., “the representational richness of a mediated environment as defined by […] the way in which [it] presents information to the senses,” and interactivity, as defined previously, “the degree to which users of a medium can influence the form or content of
the mediated environment” (p.10-1). As it derives from their definition, all three terms are interconnected; a highly immersive VE—such as an HMD or a CAVE, which surrounds the user’s field of view—will be of greater vividness, also contributing to increased sense of presence. Besides augmenting the dominant visual system of the user, enhancing other sensory modalities (e.g., through spatialized audio, olfactory displays, and haptic devices) can have an additive effect on the immersiveness/vividness of the VE, and eventually on presence.

On the other hand, immersion by itself is not a necessary prerequisite for presence, especially if we consider presence as “the concrete embodied experiences of external worlds” and not internal worlds created by abstract thoughts, reflections, and imaginings (Waterworth & Waterworth, 2003, p. 10). In that sense, virtually any experience of flow (the highly engaged state while doing an activity—discussed in detail under Section 2.4.2) can evoke a sense of presence to anybody, regardless of any technological factors. This also explains the fact that increased interactivity, especially when full-bodied interaction is involved where the kinesthetic sense is enhanced (Slater, Steed, McCarthy, & Maringelli, 1998), can also have a significantly positive impact on presence.

An abundance of studies has been conducted over these years, assessing the impact of immersion and presence on learning, with mixed results. In one such study, suspension of disbelief seemed to encourage students to engage more in explorative activities, inquiry, and risk taking, while using an immersive distance learning VE on a desktop computer (Dickey, 2005). Earlier work with immersive systems, usually involving a comparison of HMD and desktop VEs, also revealed a positive impact of immersion and learning. In such a study, immersed students constructed a better understanding about specific dynamic, three-dimensional processes of oceanography (e.g., water movement), while desktop simulations seemed to suffice for processes that could be represented statically (Winn, Windschitl, Fruland, & Lee, 2002). Moreover, immersed students spent more time to complete the tasks, talking more about their actions while doing so, and reported feeling more present in the VE than non-immersed students. Immersion has less often been evaluated in teaching non-scientific topics. Middle-school students playing an educational game on Egyptian culture in front of a large-scale panoramic display, could easier provide a show-and-tell presentation about a temple and related facts and concepts, as compared to the non-immersed students using a desktop computer (J. Jacobson, 2008).
On the other hand, not all studies investigating the impact of immersion and presence on learning have reported positive results. In a study with college students receiving different types of instruction about botany, higher immersion (using an HMD instead of a desktop) did not predict higher performance in retention and transfer measures, or program preference (Moreno & Mayer, 2002). Similarly, students using the two interactive applications in Byrne’s study (1996), offering different levels of immersion (using a desktop and an HMD), revealed no significant difference in test scores, indicating that immersion did not improve their understanding of the material presented. Nonetheless, the author discusses that world design, assessment type, hardware resolution, and student population might have impacted this result. Moreover, the increased feeling of presence reported by high-school students who used a desktop VE with increased immersive cues (i.e., an audio track), not only did not improve learning but also imposed a cognitive overload to students, who experienced greater difficulty in understanding the conceptual content (Whitelock, Daniela, Jelfs, & Brna, 2000).

This is just a limited number of examples of the vast research on the effects of immersion and presence on learning. The reported positive effects, as is obvious from the examples provided, are connected with applications where spatial understanding is important. Indeed, Bowman and McMahan (2007) conclude after reviewing an array of relevant studies, that increased immersion (involving stereoscopy, head tracking, and wide FOR23) have been proven beneficial for performance and learning (mainly information recall), when interacting with complex environments and/or when spatial understanding is significant for completing the tasks involved. Such evidence makes immersion and presence of secondary importance for the goals of this research, where focus is on interactivity and its impact on learning for a large group.

2.5.1.3 Collaboration and Cooperation

Soon after research work on VEs became popular, researchers started to investigate the added benefits of collaboration in VEs, a domain commonly known as Collaborative VEs (CVEs). Since initial applications involved better support for computer-supported cooperative work (CSCW), it was necessary that CVEs would facilitate the communication of distant collaborators. Some key features of CVEs technology suggested for enhancing communication between distant and

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23 FOR (field of regard) refers to the size of the area (in degrees of visual angle) surrounding the user in which the VE is displayed.
2.5 Virtual Environments

collocated team members in an effective manner are shared context, awareness of others, negotiation and communication, and flexible and multiple viewpoints (Snowdon, Churchill, & Munro, 2000). Moreover, in order to overcome the unnatural social isolation of participants from their surroundings using HMDs, the mainstream immersive devices of the time, researchers utilized immersive projected/desktop displays and interactive video conference environments (Traill et al., 1997).

As it was expected, this hype transferred to using CVEs for learning, most often in science education, where deep understanding of complex scientific concepts and phenomena are necessary. The basic motivation was due to the three basic cognitive benefits of collaboration (articulation, conflict, and co-construction), through which conceptual change can be achieved in learners by resolving conflicts engendered by collaborative activities (Crook, 1994). At the same time, there was a big opportunity for connecting multiple learners in a common virtual space (e.g., a virtual classroom) for the purposes of learning (or even entertainment). The key added benefits of such distributed synthetic environments for learning, as suggested by Dede (1995), are telepresence of geographically remote learners via virtual avatars and presence inside imaginary—nonetheless realistic—worlds. More about such research, employing multi-user VEs (MUVEs) over the Internet, in the next section.

Work that followed involved the assessment of the role of collaboration inside VEs, as a means to increase engagement and learning through peer activities. Again, mixed results were reported about the effectiveness of collaboration to promote learning in VEs. In one study, high-school students worked in virtual dyads wearing head-mounted displays and communicating through an intercom system, trying to learn concepts related to global warming (Jackson & Fagan, 2000). Although no direct evidence of learning could be accounted to collaborating in the immersive VE, researchers reported observations of conceptual change, such as dealing with conflicts, articulating beliefs, and co-constructing theories. In a similar, but informal, study distributed participants using HMDs had to learn together about concepts of physics in different VEs, where collaboration was necessary due to the complexity of the tasks (Brna & Aspin, 1998). Researchers reported the participants’ inadequacy of using a scientific approach for the exploration of the environments, while no reference is made about the effectiveness of the VEs to support the development of a shared conception of the problem, which was set as one of their basic evaluation goals.
The NICE project involved two teams of elementary student couples work together from two remote locations using different multiuser VR setups (a CAVE and an Immersadesk), in order to tend a virtual garden (Roussos et al., 1999). Findings of the study include the observation that student groups perceived the activities as competitive and kept fighting over who will get control of items, leaders/drivers of the experience paid more attention to the subject than the less active group members, and avatar representation as a vehicle for social interaction was detrimental to science learning. Although no specific learning gains could be attributed to collaboration, researchers reported that this might be due to inadequate instructional design in order to support the learning activities through cooperative work.

The Round Earth Project was informed by these lessons and involved two remotely located students having to work together in a VE using two different interfaces, in order to understand that the earth is spherical, contrary to their everyday experiences (A. Johnson, Moher, Ohlsson, & Gillingham, 1999). Pilot studies with middle-school students did not reveal a significant improvement in their ability to remedy this common misconception. Although researchers report observations of learning instances related to specific knowledge components, they noticed that overall students treated the experience as a video game, with active communication happening only on task-specific topics. As we notice from these examples, most of the work with CVEs involves distributed participants, usually with two students in highly immersive setups (i.e., physically and socially isolated), with minimal formal evidence of collaboration’s ability to support learning. This constitutes yet one more motivating factor for pursuing our research, where focus is placed on larger collocated groups of students in less immersive VEs, where social face-to-face interaction is possible.

In one of the few studies involving small group collaboration in VEs, Slater and Schroeder (2000) compared groups of three adults interacting in a shared virtual space (one using an HMD and two on desktop computers) and then in a similar real environment, in order to complete a simple task. Results of this experimental study indicate that leadership seems to be enhanced by greater levels of immersion, presence and co-presence (i.e., the feeling of interacting with real people) are positively associated (causality cannot be defined), and even limited avatar representation can be respectful and elicit personal emotions to social situations, such as discomfort and embarrassment. Although the aim of the study was not to assess learning or task performance, we still consider the implications of how virtual and real social relations can affect
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collaboration, rather important. Small group (tripartite) interaction has also been used as a means to investigate the relationship between presence and co-presence in a CVE (Casanueva & Blake, 2000). According to the findings of the study (using undergraduate students), a high sense of co-presence in CVEs is mediated by group collaboration and interaction in the virtual world, and simply having virtual representations of participants is not sufficient. These studies provide an insight of how social presence might be affected by physical collocation, but again they differ compared to the common student group setup of a museum visit.

Finally, we need to mention that another line of CVE research, not directly related to learning though, was on the use of collaboration for performing common tasks in a virtual world. Some researchers doing such work on simultaneous object manipulation in CVEs have used the term cooperative, rather than collaborative, to emphasize this close user-to-user interaction to perform a task (Pinho, Bowman, & Freitas, 2002). However, in our research we use collaboration to express this simultaneous, non-division of labor, as provided by the definition—we have embraced at the outset of Section 2.3—offered by Roschelle and Teasley (1995); i.e., “a coordinated synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem.” At the same time, in a multi-user environment users cannot work concurrently on the same problems all the time, and different learners will have to assume different roles, demanding different cognitive skills. This relation of roles to cognitive processes has been suggested to allow collaborative partners to concentrate on different aspects of the “dialogue,” thus relieving the cognitive load on an individual and elevating the educational benefit of the collaboration as a whole (Burton, Brna, & Treasure-Jones, 1997). Thus, it would be important to investigate how the degree of active involvement in the experience can affect the psychological/behavioral engagement and the learning gains for individual participants.

2.5.1.4 Multiple representations

Since the advent of interactive multimedia programs, it was believed that one of the strongest advantages of the technology for learning was its ability to provide a combination of multiple representation of a concept to learners. This added learning aid, which could be even achieved with illustrations accompanying text material, allowed learners to experience related information in an context that facilitated comprehension of the material (Levie & Lentz, 1982). Moreover, multiple representations have been shown to generally lead to the development of an enriched
understanding of the material, as opposed to the more “fragmented and superficial learning” of text or non-interactive multimedia presentations offering information through only one channel (Y. Rogers & Scaife, 1998). This multimodality of information presentation allows learners to construct multiple models of the relationships between the concepts presented, forming a more complete mental model of the material.

In the realm of VEs, VR technology not only enables multiple representations of concepts in an effective manner, but can also immerse the learner in environments which cannot be reachable otherwise. Indeed, the ability to easily switch between multiple perspectives or frames of reference (e.g., exocentric and egocentric views of a virtual object/world), can facilitate understanding of complex phenomena by combining embodied/concrete learning with more abstract/symbolic insights (Dede, 2009). On the other hand, VEs provide the opportunity to immerse learners in environments that are impossible to visit (e.g., inside the human body) and expose them to phenomena which could not be experienced physically (e.g., at the molecule level). Winn (1993) suggested three kinds of knowledge-building activities unique to VEs, which can leverage the power of multiple representations: size (altering the relative size of learners to the VE), transduction (presenting information that is not readily available to the human senses), and reification (creating representations of objects and events with no physical form).

Maybe one of the first studies assessing the impact of multiple representations on the students’ understanding of science education was ScienceSpace (Dede, Salzman, Loftin, & Ash, 2000), also discussed above as a general example of using VR for learning. Researchers hypothesized that the VEs developed could enable representation of complex scientific phenomena in multiple perspectives, helping learners gain experiential intuitions of these phenomena by increasing the salience of important factors and their relationships. Besides the usability problems, researchers reported results from formative evaluations with high-school students using NewtonWorld (teaching Newtonian physics) and MaxwellWorld (teaching about electrostatic fields). In NewtonWorld, no significant learning improvement between pre/post-tests was found, but most students appreciated the option of using multiple 3D viewpoints. Comparing MaxwellWorld to textbook/lectures proved more effective in that it helped students develop an in-depth understanding of the distribution of forces, by allowing 3D manipulation of the electric field; nonetheless, the comparison with a 2D desktop application did not reveal significant learning gains (i.e., a transformation of the users’ mental models).
Multiple representations have been also used in CVEs, where users have a different view of the same VE. In the *Round Earth Project* (A. Johnson et al., 1999), the user in the CAVE had a first-person view through a spaceship, while the ImmersaDesk user was in the mission control, having an exocentric (or God’s view) of the world. Although no significant remedy of the misconception of the ‘flat Earth’ was reported in this study, we still consider this an innovative design using multiple frames of reference in a CVE. Similar work from the same research group includes the exploration of multiple representations using collaborative virtual microworlds (called QuickWorlds) in elementary school science classrooms (A. Johnson, Moher, Ohlsson, & Leigh, 2001). Although no findings are reported from this work, we consider important their statement that they have found no ‘silver bullet’ for assessing the effectiveness of their interventions on learning and, having recognized the inadequacy of media comparison studies, they heavily rely on post/pre-test score differences.

Overall, we notice from this small representative sample of studies that multiple representations in VEs have been solely used for conceptual learning—mostly learning (abstract) complex scientific concepts. Dede (2009) suggested that multiple perspectives are an immediate benefit of immersion in a VE; however, we argue that multiple perspectives, or frames of reference, are mainly a property of 3D representations (e.g., any desktop VE can utilize them) and that not all immersive VEs need to employ them in order to be effective as learning tools. Consequently, we consider applying multiple representations of low importance for our research, which is more focused on assessing cultural heritage knowledge acquisition (i.e., no conceptual change is necessarily required), using a low-immersive VE to avoid social isolation.

### 2.5.2 Educational MUVEs Research

This section constitutes an extension of the previous one, providing prominent examples of VE studies that we consider to be closer to our own research, by employing multiuser interaction. Most such research involves the use of the contemporary, Internet-enabled genres of MUVEs and MMOGs. Although not explicitly intended for learning, MUVEs and MMOGs, such as *Second Life*, *Action Worlds*, and *World of Warcraft*, have been frequently used for educational purposes inside (Egenfeldt-Nielsen, 2005; Squire, 2005) and outside (Steinkuehler & Alagoz, 2010) the classroom. A second, less frequent avenue of research is the use of custom MUVEs for intentional

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24 MUVE: Multi-User Virtual Environment; MMOG: Massively Multiplayer Online Game
learning of large groups of students. In both cases, researchers report increased motivation and engagement deriving from the gaming, immersive, and social attributes of these systems, eventually leading to enhanced learning outcomes. In the following paragraphs, we will review some prominent MUVEs, mostly of the latter kind, which although they involve distributed interaction, we still consider relevant to our research due to simultaneously engaging large student groups in the learning process.

In a long study (spanning over multiple years) involving distance learning for K-12 students, three projects using on-line VEs on historical, religious, and sociological issues were assessed for their effectiveness as ICT-based learning tools (Di Blas, Poggi, & Reeves, 2006). The evaluation revealed students’ improvement in knowledge (i.e., understanding history), skills, and attitudes, as expressed by both students and teachers. The collaborative nature of the experience enhanced the students’ sense of being responsible for the success of the whole team. Levels of engagement, flow, and virtual presence have been shown to be high, while competitive features seemed to be highly appreciated and mitigate any technical failures or poor aesthetics. Although the projects involved simultaneous collaboration of classrooms, only two users per classroom had dedicated avatars in the 3D worlds.

*Quest Atlantis* (also mentioned in Section 2.4 on Serious Games) is a 3D MUVE used by thousands of students within classrooms for intentional learning (Sasha A. Barab et al., 2012). Students immersed in the game as protagonist learn through transformational play, which involves having changing a problem-based fictional context collaboratively, in order to facilitate conceptual understanding of information. Evaluation involved comparing a game-based and a story-based classroom on persuasive writing with 9-15 year old students. Besides the significantly greater learning gains and engagement levels, the gaming MUVE enabled numerous collaborative interactions between students, as opposed to very few in the story-based classroom. Nonetheless, as the authors note, these collaborative instances had more to do with making sense of the narrative, while actions within the virtual world could be performed individually.

*River City* is another custom MUVE for intentional learning, where students learn about hypothesis formation and experimental design through collaboratively identifying and making inferences about problems in epidemiology (Ketelhut, Dede, Clarke, Nelson, & Bowman, 2007).

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25 ICT: Information and Communication Technology
The MUVE, shown in Figure 2-5, is basically an online role-playing game (RPG), where students have to work together in teams, talking with each other and with virtual agents using chat, in order to discover the source of a disease. Using the MUVE with three different instructional approaches (guided social constructivist, expert modeling and coaching, and legitimate peripheral participation) resulted in substantial gains in knowledge and skills in scientific inquiry, as compared to conventional instruction.

![Image](http://example.com/image.jpg)

**Figure 2-5.** The interface of the River City is split in four different workspaces.

The authors stress the importance of combining information recorded from student activities in the MUVEs (i.e., logged data) with assessment data (both standardized like pre/post-tests and performance-based), in order to draw useful conclusions about the degree of learning in these environments. This has been a very influential work in the domain of educational MUVEs in the past decade, but have solely been used in formal learning settings (classrooms), where assessment of student performance might affect the attitude of the students and eventually the learning outcome.

A popular online MUVE, called Whyville\(^\text{26}\), has been used for assisting students increase their understanding of natural infectious diseases, after being integrated with an existing science curriculum (Neulight, Kafai, Kao, Foley, & Galas, 2006). The study involved two middle school

\(^{26}\) More information at [http://whyville.com/](http://whyville.com/)

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classrooms using the simulation sporadically during and after school hours, over a period of a ten-week science course. Findings indicated that students' reasoning about the causes of natural diseases was significantly improved after using the MUVE, but most of the students still provided pre-biological explanations, which was attributed to the difficulty of the subject. Also, the immersiveness of the MUVE was believed to help students make connections between the virtual and real diseases in a safe manner; however, no report is given about the impact and effectiveness of collaboration on learning and/or engagement.

These MUVEs, however, are distributed and are missing the benefits of collocated collaboration deriving from the physical co-presence of other learners. Moreover, in most cases, researchers tried to embed the content of the applications in the curriculum of the school, performing the studies inside a classroom environment. Although this “formality” of the content (i.e., having the etiquette of formal education) might not be negative by itself, it deprives the experience of the potential benefit that a more informal instructional approach might bear (e.g., that students will not be assessed on their performance). Additionally, the setting itself is believed by some museum education researchers to impact learning, by means of affecting the students’ expectations and motivation to participate (John H. Falk & Dierking, 2000).

2.5.3 Using VEs for Informal Learning

As we have seen earlier, previous research has mainly focused on exploiting VEs for constructivist and contextual learning (Dede, 1995; Roussos et al., 1999; Winn et al., 2002), but rarely have these practices been integrated with the entertaining character of museum visits. Based on the assumption that museums are also appropriate spaces for constructivist, experiential, and situated (or contextual) learning, as expressed by various education researchers (Allen, 2004; Hawkey, 2004; Hein, 1994; Sefton-Green, 2004), it makes sense to explore the potential learning benefit of their integration with VEs, especially for children visitors (Roussou, 2000). Some of the few examples of such work are presented below, with emphasis on research happening in actual museums and in some cases includes collaboration, or at least presentation, of the content to multiple participants. We exclude here work that involves audience interactivity in large spaces (e.g., dome theaters), examples of which are presented under Section 2.2.4.

One of the earliest examples of using VEs for informal learning was the Virtual Gorilla Exhibit tested at the Zoo Atlanta, in order to teach visitors about gorilla behaviors and social
interactions in a virtual simulation of a natural habitat (Allison, Wills, Bowman, Wineman, & Hodges, 1997). The project assumes the practice of multiple representations in an immersive VE, to both allow students to explore inaccessible gorilla habitats but also experiencing gorilla life through a first-person point of view. Preliminary user testing with elementary and middle school students, indicated that they enjoyed the experience and learned about gorilla attitudes, interactions, and group hierarchies by being immersed in the virtual habitat (using an HMD). However, no formal evaluation was conducted in this research.

A research exploring the potential for social interaction offered by museums, utilized a collaborative system using virtual and augmented reality (Asai, 2010). The system was designed to encourage mutual communication between children and parents, as a means to facilitate learning about lunar surface exploration. A user study conducted in the Modern Industrial Science Museum with 155 participants (85% visiting family members) indicated that parents can facilitate children’s interpretations of the content, through playful interactions encouraged by the collaborative learning setup. Moreover, a high percentage (98%) of correct responses was reported for all participants, although prior knowledge has not been assessed and no decisive conclusions can be made about the setup’s efficacy as a learning tool.

In another exploration of the potential of VEs in museums, the Natural Museum of American History and the University of Iowa build “This Old Digital City,” a VE acting as an interface to historical archives (Severson & Cremer, 2002). Part of their motivation was to engage pre-teen and teenage visitors who are not easily attracted by conventional museum exhibitions, hypothesizing that the blending of physical artifacts inside the VE might afford more fun, engaging, and memorable educational experiences. The system included a large-scale projection screen installed in a theater and was controlled by a custom user-interaction panel with a joystick. Although no formal evaluation was reported in this study, an interesting finding was the observation that many parents prompted their children to pass control to their siblings (only one “driver” was allowed at a time), in order to “equalize the experience.”

Although most research with VEs in museums involves science education, there have been some examples where the learning objective involves cultural heritage (similar to our research). Such an example are the virtual tours employed by the Earth Theater of the Carnegie Museum of Natural History, where interactive content projected on a half-dome screen is merged with live
docents to provide a unique learning experience to large audiences. The shows involve either a
tour guide using a wireless controller to navigate through the VE, adapting the virtual tour
according to the needs of the moment, or one student controlling a game and responding to
questions with the help of her peers. Evaluation has been only carried out only for the latter case,
where being immersed inside a fictional Egyptian Temple (game called Gates of Horus) has been
shown to afford greater comprehension of Egyptian culture, especially for students with lower
spatial reasoning abilities (J. Jacobson, 2011).

Group learning has been also facilitated using portable (inflatable) domes projecting
material on various topics. As an example, The Ghosts of Tikal is an interactive game using a
virtual reconstruction of a classic Mayan city, allowing middle and high school classes to study
this ancient civilization and get involved in group problem-solving (Sumners, Schloss, Handron,
& Jacobson, 2012). The game has been informally tested with different samples (i.e., students of
different age and abilities), with or without pre-simulation preparation, using different group
implementation scenarios (single or alternating student control), and different levels of teacher
involvement. Suggestions deriving from their observations include: group size and teacher
intervention needs to be adapted according to student needs; providing flexibility in the game to
enables engagement of students with different attention spans; and actively involving the teacher
in the process may prove beneficial for the learning of his students.

Finally, there are some spaces of informal learning employing VEs to entertain and educate
their audience, without having, however, an agenda for conducting formal research. Such an
example is the Foundation of the Hellenic World in Athens, Greece, which has been developing
and distributing VEs to the broad public for almost two decades now (Christopoulos & Gaitatzes,
2009; Gaitatzes, Christopoulos, & Roussou, 2001). Although their work might be of high quality,
offering a significant service to their young audiences, we have no way to estimate the
effectiveness of their practices for disseminating knowledge. Similarly, others have been involved
with immersive cultural heritage VEs, focusing more on the technical challenges imposed by the
application design and much less on the learning efficacy of their approach (e.g., S. Chen, Pan, &
Zhang, 2012). Both of these cases are excluded from our review for obvious reasons.

Overall, we believe it becomes obvious from this brief review of related work on VE use
in museums that there is an apparent lack of formal experiments in museum settings, as far as
assessing both their ability to actively engage a large audience with the experience and their potential to support meaningful learning through social interactions.

2.5.4 Section Summary

Virtual environments (VEs) have been used for educational purposes for more than two decades now and have been suggested to bring lots of advantages to learning\(^{27}\). Initially, we reviewed these educational promises, presenting their theoretical grounds and making connections with existing learning theories, such as constructivism, situated learning, guided-inquiry, and experiential or discovery learning. We also elaborated on specific VE properties and how they might aid learners construct understanding, giving specific examples from the literature either supporting these claims or not. The ones we considered more important are: interactivity and autonomy (the ability of the user to control the VE and its contents), immersion (the technical attribute of the system to surround the user) and presence (the sense of ‘being’ inside the virtual world), collaboration and cooperation (enabling social interactions within the VE), and multiple representations (providing various frames of reference of a virtual object to the learner).

In the last two parts of this section we focused on specific uses of VE, which we believe are pertinent to our own research. First, we reviewed examples of multiuser VEs (MUVEs) and provided findings from related research, which examines their effectiveness for supporting learning to large audiences. Most of the research so far on MUVEs has focused on distributed virtual worlds through the Internet and/or with groups of students working within the classroom (formal education), but we still consider their lessons learned important for our research. Second, we reviewed some uses of VEs for informal learning, mostly with studies being conducted in museum spaces. Although not many of them employ multiuser interaction (the ones that they do are focused on parent-children interaction), we value the effort of the researchers to attempt to assess learning within this complex sociocultural context.

\(^{27}\) Work on VEs and games has been in some cases intertwined and although we tried to separate it for the sake of this review, we consider that some findings cannot be considered in isolation.
Chapter 3

Conceptual Framework & Testbed Design

The detailed literature review of related work we have done allowed us to get a better understanding of the existing learning theories and how these have been used over the years, in conjunction with technologies such as serious games and virtual environments, to increase knowledge dissemination in formal and informal education. In this chapter we first present the conceptual framework of our research, which combines existing learning theories and technological elements to fill a specific identified gap; i.e., facilitate group learning of a large audience collocated in a common (museum) space. Then, we present our research questions and the hypotheses related to each one of them. Last, we present the testbed application that we have built as an experimentation platform for validating our research hypotheses.

3.1 Conceptual Framework

After exploring the major theories of learning and interactivity, and research work being done with collaborative virtual environments (CVEs) and serious games, we extracted those elements that we think can nurture the type of free-choice (or informal) learning happening in museums. Figure 3-1 depicts our conceptual framework, which identifies engagement and social presence as significant contributors of learning, and illustrates how they are affected by the personal and social context of collaborative interactions between children and technology. Hopefully, this framework will be helpful in presenting the scope of the current research within the larger body of work, which has mainly focused on the learning benefits of the individual elements (e.g., the role of interactivity in learning) or technologies (e.g., serious games for learning).
3.1.1 Explanation of Framework

The above framework consists of three parallel dimensions, comprised of two different collaborative technologies (the side ones) and another framework (the middle one), whose elements have been suggested to predict, or contribute to, learning. More specifically, collaborative serious games and virtual environments are the two technologies that have been extensively studied for their educational benefits, while the Contextual Model of Learning (CML) is the framework that has been suggested by Falk and Dierking (2000) to predict free-choice learning in museums. The main premise of our framework is the combination of the CML with collaboration in gaming VEs, for enhancing the museum visitor experience and facilitating learning in (large) student groups.
The framework is broken down further in two contexts, the personal and social, which appear in two separate horizontal axes in Figure 3-1. The personal context includes all the elements of the technologies and the CML factors that have been shown to affect the individual experience of the game/VE user or museum visitor. These elements have been connected to enhanced engagement (e.g., interactivity and autonomy are considered significant contributors to engagement, as has been discussed in Section 2.2), which in turn has been shown to increase learning in some situations. Malone and Lepper’s theory of intrinsic motivation for enhancing learning outcomes by making learning more fun, and thus more engaging (Thomas W. Malone & Lepper, 1987), is such an example from the serious games arena. Moreover, students’ active participation with imaginary worlds that are ingrained in their cultural background—by means of beliefs, values, and expectations—is believed to increase their emotional involvement and consequently learning (Dede, 2009); this is an example from the realm of VEs.

The social context involves the technological elements and CML factors that are believed to contribute to the enhanced social experience of the collaborative game/VE users or museum group visitors. Elements such as social play/interaction and empathy in collaborative computer-mediated environments have been shown to increase social presence, especially when participants are working with or competing against friends (Gajadhar et al., 2008). Even in distributed collaborative VEs, the sense of being together (social presence) has been shown to contribute to increased enjoyment, enthusiasm, and improved knowledge and skill acquisition (Di Blas et al., 2006). At the same time, the CML predicts that increased learning derives from the opportunities for within-group mediation and facilitation (by more expert peers or guides), offered by the collocation of visitors in the museum space.

It is one of the basic goals of our framework to assess the effectiveness of the integration of the elements of the involved technologies and the social context factors of the CML during collocated collaboration, for increasing social presence and eventually learning. Such elements and factors have been examined in isolation about their impact on learning, and we hypothesize that their integration bears considerable potential for the orchestration of learning, in collocated groups of students (such as the ones found in museum group visits). In the next section we elaborate on our definition of orchestrated learning, as a product of the situated interaction of students in the same physical space.
3.1.2 Situated Orchestrated Learning

In this research, we use the term *orchestrated learning* to denote the type of learning that occurs through the intentional facilitation of coordinated collaborative activities within a VE. Others have used the same term to describe the “cooordination of learning episodes,” as a means of orchestrating the interactions between learners and resources within a classroom (Crook, Harrison, Farrington-Flint, Tomás, & Underwood, 2010). Based on our own definition, we have named our framework, and consequently our testbed application/game described in Section 3.3, *C-OLiVE: Collaborative Orchestrated Learning in Virtual Environments*. It has been shown that encouraging collaborative activities by design through the demand of inter-group coordination increases social (inter)actions between participants (B. Brown & Bell, 2004) and we believe to also have a positive impact on learning.

Moreover, through our extensive literature review, we identified that the basic premise of learning occurring in VEs is the same as the one for free-choice learning spaces like museums. This has to do with the fact that the protagonist of the fictional world is engaged in realistic activities that can change the fate of the world (Sasha A. Barab et al., 2012), in a similar fashion that the visitor of a museum is engaged with authentic activities that reconstruct real-life experiences and concepts (John H. Falk & Dierking, 2000). Similarly, learning in C-OLiVE is achieved by engaging the students in authentic activities within a simulated environment and having them negotiate their actions in the physical space, afforded by the collocated collaborative nature of the game. Situating learners in authentic problem-solving activities is not only considered to be a major leverage of learning in physical contexts such as classrooms (J. S. Brown et al., 1989), but also one of the main benefits of learning within virtual environments (Dede, 2009).

Furthermore, adopting this metaphor of learners as members of a musical orchestra has other connotations for our instructional approach besides emphasizing the demand and benefits of coordinated action. Musicians are totally engaged in their performance and their actions are driven by their intrinsic passion for excellent acoustic results, similar to how games like C-OLiVE match the goal and process of the game with the learning outcomes. This engagement with free-choice tasks where extrinsic rewards are absent has been connected to increased sense of the flow experience (Csikszentmihalyi, 1990), but also to enhanced learning due to its intrinsically motivating power (Thomas W. Malone & Lepper, 1987). Additionally, the increased levels of fun
3.1 Conceptual Framework

and engagement deriving from peer collaboration within groups visiting museums (John H. Falk & Dierking, 2000) or working together in classrooms (de Freitas, 2006), might in some cases reinforce learning outcomes.

Another attribute of orchestrated learning, as defined in this work, that applies aptly to CVEs and museums is the rich sociocultural context experienced by the group members. Similar to how orchestra members participate in a shared community of practice, where common goals and understanding are necessary for its success (Lave & Wenger, 1991), C-OLiVE provides a (virtual) community of workers where players have to negotiate their actions and plan a common route through distributed decision-making. Musicians can assume different levels of participation according to their skill level the same way that C-OLiVE allows players to assume more or less active roles based on their knowledge or gameplay capacity. Finally, learning is facilitated through interactions with more capable peers (musicians or players) or a tutor (conductor or curator), which has been shown to improve individual learning benefits (Vygotsky, 1978). Likewise, Falk and Dierking consider the sociocultural mediation by others, either co-visiters or museum educators, a considerable contributor to the museum contextual learning experience (John H. Falk & Dierking, 2000).

3.2 Research Overview

In trying to investigate the effective merging of the elements used in our framework (see Figure 3-1) for achieving an enhanced museum learning experience for a group of students, we will address the following research questions (presented in more detail under Section 1.3):

RQ1: What is the effect of the level of interactivity on learning in a gaming, collaborative VE (CVE) for more than two collocated participants?

RQ2: What is the interplay between level of interaction, game experience, social presence, and learning during within-group collaboration in physical space?

RQ3: What is the effect of culture, prior knowledge, and the style of information presentation (facilitated or not) on learning using a gaming CVE in a museum-type setting?

RQ4: How does the level of involvement of a large audience of students affect game experience, social presence, and eventually learning during collocated collaboration?
Besides this set of main questions some other sub-questions about other factors which have been shown to affect informal learning, will also be evaluated. These have mainly to do with the CML, which is reflected in the middle dimension of our conceptual framework. More specifically, we will attempt to investigate the effects of the experiment type on the outcomes; i.e., how an actual museum visit, and the expectations and motivation deriving from it, can affect enjoyment and learning, as compared to a controlled study environment. Also, we will try to gauge the students’ interests and beliefs about the domain knowledge, and make conclusions about the degree these have affected their overall experience and learning gains.

A summary of our approach in responding to our research questions, including the specific elements that will be addressed by each study, and the scope and type of experiment (controlled or ecological) are presented in Table 3-1. Overall, we plan to conduct two controlled and two ecological evaluations; the first three will be experiments for assessing the most important elements considered from the framework, while the last one is an informal case study for evaluating the effectiveness of the design guidelines, derived from the main findings and conclusions of the formal experiments.

<table>
<thead>
<tr>
<th>Experiment Type</th>
<th>Research Questions</th>
<th>Framework elements considered</th>
<th>Experiment Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>I – Controlled*</td>
<td>Q1, Q2</td>
<td>Interactivity/autonomy/choice &amp; control</td>
<td>Small group interaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Within-group sociocultural mediation</td>
<td></td>
</tr>
<tr>
<td>II – Ecological*</td>
<td>Q1, Q2, Q3</td>
<td>Interactivity/autonomy/choice &amp; control</td>
<td>Small group interaction during museum visit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Within-group sociocultural mediation</td>
<td>Comparison between cultures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Facilitated mediation by others</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prior knowledge and interest</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motivation and expectations</td>
<td></td>
</tr>
<tr>
<td>III – Controlled</td>
<td>Q1, Q2, Q4</td>
<td>Interactivity/autonomy/choice &amp; control</td>
<td>Large group interaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Within-group sociocultural mediation</td>
<td></td>
</tr>
<tr>
<td>IV – Case Study</td>
<td>Q5</td>
<td>Overall evaluation</td>
<td>Large group interaction during museum visit</td>
</tr>
<tr>
<td>Ecological</td>
<td></td>
<td>Refine design guidelines</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-1. Summary of our research approach (* completed studies).
3.3 Testbed Application

In order to explore our research questions and validate our conceptual framework, we decided to develop a simulation game that supports collocated collaboration, initially for one to three players. More specifically, this is a virtual environment that teaches students about olive oil production using a game-style interface, which we call C-OLiVE: Collaborative Orchestrated Learning in Virtual Environments. The VE is a steam-powered olive oil factory of the mid-1900s with the actual machinery of the time, which players have to operate in order to produce olive oil. This application is going to be our test bed throughout the whole research, with modifications that will enable us to test our research questions. Our audience is middle-school students as both the dominant visitors of informal learning spaces during school field trips and avid users of gaming technology.

The topic was chosen for various reasons. First, due to its suitability in enabling us to control the first two key factors of the CML’s personal context (John H. Falk & Dierking, 1992): motivation and expectations, and prior knowledge, interests, and beliefs. Testing the game with different populations, having diverse cultural backgrounds, interests, and motivation to learn about the topic, will allow us to assess the effects of these factors on the game experience and learning outcomes. Thus, the populations that we chose for our first two experiments come from the US and the Greek culture, with the latter having historically a much larger exposure to the domain knowledge, as one of the largest producers of olive oil in the world. Second, the nature of the application affords ample opportunities for collaborative activities, since the tasks that workers had to do to operate the machinery of the factory at the time involved quite a lot of manual labor. Last, the factory as a closed, well-defined space enables free exploration and manipulation of virtual objects (necessary requirement for increasing autonomy/control), without having to artificially constrain the players’ movements.

3.3.1 C-OLiVE Implementation

C-OLiVE is an accurate representation of an actual steam-powered olive oil factory on the island of Lesvos in Greece, containing exact 3D replicas of the machinery used at the time. The factory seized operation in the 1960s and became a museum about industrialized olive oil production in 2006. Figure 3-2 shows real and virtual images of the factory and its machinery. Machinery used
for the production of olive oil were included in couples (there were actually four in the real factory, as can be seen in some pictures) to enable simultaneous interaction and distribution of labor between participants. The system is designed so far to support one to three simultaneous players, but will be expanded to facilitate audience interaction for the purposes of our last two studies (more under Chapter 5).

![Real and virtual olive oil factory](image)

**Figure 3-2.** Pictures of the real (top) and the virtual (bottom) olive oil production factory.

The VE was built using the Vizard VR toolkit\(^{28}\), and 3D Studio Max and Maya\(^{29}\) were used for the construction of the factory and the 3D models. The machines were high resolution models used by

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\(^{28}\) Vizard is a Python-based toolkit developed by WorldViz (http://www.worldviz.com/)

\(^{29}\) 3D Studio Max and Maya are both developed by Autodesk (http://www.autodesk.com/)
the museum for their video productions and had to be optimized for use in a real-time VR environment, mostly through complete reconstruction with less polygon detail (Figure 3-3 depicts such an example with the press head before and after polygon reduction). Photorealism was not considered important for the educational use of this application, as research has shown that increased visual fidelity is not always beneficial for improved learning (Alessi, 1988; Herrington, Reeves, & Oliver, 2007), as compared to cognitive realism—i.e., the appropriate design of a simulated task that affords realistic problem solving (P. Smith, 1986).

![Figure 3-3. The press before (left) and after (right) polygon reduction achieved through remodeling.](image)

The game supports different kinds of game controllers, but for the small group interaction (up to three players) we have decided to use wireless Xbox controllers due to their popularity as gaming devices and rich available inputs (control mappings are explained in the next section). For the audience interaction paradigm we are considering different types of devices to accompany the game controllers, with tablets (e.g., iPads) being the most dominant so far. The device choice will be determined once we decide on the different types of activities and interaction techniques that will be used to perform them.

Players have a first person view in the VE with individual camera viewpoints for each player (see Figure 3-4). Our initial design involved a combination of individual and shared viewpoints depending on the task at hand, but we eventually decided that this might confuse the players, in addition to decreasing autonomy as a result of the restricted navigation. Control and pace has been shown to be a catalyst for effective assimilation of information in museums and similar spaces of exploratory learning (Allen, 2004; John H. Falk & Dierking, 2000), thus enabling individual navigation and object manipulation was deemed significant for our game design.
A single large front-projected display (non-stereoscopic) is used by all players sitting next to each other. We chose not to employ a fully immersive VE for three basic reasons. First, immersive technologies (e.g., head-mounted displays, stereoscopic screens, and CAVEs) are rather costly and not easily adopted by museum spaces. Second, immersion has not always been connected with improved learning gains (Herrington et al., 2007), unless spatial understanding is of high importance (Bowman & McMahan, 2007). Last, social interaction is pivotal for our work and some immersive technologies tend to hinder opportunities for face-to-face communication, by isolating or limiting the users’ perception within the virtual environment (e.g., using HMDs such as the Oculus Rift or wearing stereo glasses within tracked spaces).

### 3.3.2 Game Interface, Mechanics, and Controls

The game interface used in our experiments so far is displayed in Figure 3-4. This is the setup for three players interacting at the same time, and includes the individual viewpoints and a top-down view map of the olive oil production factory. The individual interface elements and basic game mechanics, as well as the control mapping used are explained below.

![Figure 3-4](image) The three-player game setup with individual viewpoints and a top-down view map of the factory.
Each window has a side panel containing vital information about the game. The player’s name and color, her inventory, and feedback for any action attempted are all displayed there. When the player selects a tool from the inventory it is highlighted and appears in the middle of her viewport (e.g., the bottom-right player in Figure 3-4 has selected the wrench). A top-down map of the factory is also shown at the top-right of the display; it contains avatar locations, warnings, and information messages about the status of the machinery, and the game score. Players have to attend to the alerts on the map and troubleshoot problems as quickly as possible. Points are added for every correct action while points are lost when a problem is not solved for a prolonged period. A schematic explanation of all the interface elements is presented in Figure 3-5.

**Figure 3-5.** A visual explanation of the game interface (factory map and player viewpoint).
Players can move freely inside the factory walls (collision detection prevents them from exiting the factory or going through machinery) and can also look up and down (e.g., the player in Figure 3-5 is looking slightly downwards). Players can also grab tools (using their hand) and apply them on machine parts, getting a feedback message for every action attempted. Tools can be dropped when not needed any more, or when the inventory is full (only three tools can be carried at any given time). The control mappings are presented in Figure 3-6. All main processes (e.g., a belt turning, a pulley rotating, a press shaft moving, or a needle spinning) are shown as animations in the virtual world, with a relatively realistic manner to increase student understanding.

**Figure 3-6.** Control mappings (i.e., virtual actions assigned to Xbox controller buttons)

Control choices were tested during our pilots to verify that they are usable and easy to remember and execute by most students. We chose navigation with one joystick over the—more popular in commercial games—distinct translation and rotation with two joysticks, because we noticed that expert game players could easily adapt to this mapping, while novice ones struggled with the distinct assignment of navigation controls. Also, head tilting always reverts back to looking at the horizon once the right joystick is released, to avoid students walking around the virtual world in a strange viewpoint perspective (e.g., looking at the floor). Finally, redundant controls of common actions (e.g., executing an action) were provided for extra convenience.
A finite state machine (FSM) is used to handle all the events happening in the factory based on user input and the current state of each machine. An FSM has been defined for each machine, and a factory FSM monitors all events and distributes messages and actions to the machine(s) involved in an interaction (e.g., a player applies a tool on a machine part) or an event (e.g., a timer expires indicating that a process finished). Moreover, the machinery FSM contains all the information, warning, and interaction feedback messages that are presented during game play. The FSM was compiled using Microsoft Excel to facilitate editing and review by domain experts during the implementation process.

As an example, let us take one of the first tasks necessary to operate the factory, which is to load the steam boiler with fuel (see Table 3-2). All machines are initially in an idle state and receive an entry input, once the application starts. The type of input defines the next state of that machine, the output displayed in the interface (in this case, an alert on the boiler), and any messages related to the alert (a/machine/), a task performed by someone in the factory (i//), or feedback to specific user interaction (in this case, a description of the problem with the boiler appears in the yellow box at the bottom of the map; see Figure 3-5). If a player performs a wrong action (e.g., try to grab the coal/olive pomace by hand, as shown in the second row), then the machine stays in the same state and an informative message is displayed on the player’s side panel as feedback. If the user performs the correct action (i.e., use the shovel to load the boiler with coal/olive pomace, as shown in the third row), then the player receives positive feedback, while the machine switches to the next state (i.e., the boiler is now loaded). At the same time, the machine receives an entry input and sends the output commands to the program separated by semi colons (in this case, an animation for loading the boiler and increasing the score by 10), while a message appears at the top of every window (inside the blue border) informing all players about the factory status.

<table>
<thead>
<tr>
<th>Current State</th>
<th>Input</th>
<th>Next State</th>
<th>Output</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>boiler/idle</td>
<td>entry</td>
<td>error1_boiler</td>
<td>a/boiler/The steam boiler is not working, you need to start it up!</td>
<td></td>
</tr>
<tr>
<td>boiler/idle</td>
<td>hand_coal</td>
<td>boiler/loaded</td>
<td>You need to use a tool to load some of the olive pomace inside the boiler's furnace</td>
<td></td>
</tr>
<tr>
<td>boiler/idle</td>
<td>shovel_coal</td>
<td>loading_boiler; score[10]</td>
<td>You are shoveling olive pomace in the boiler, which is necessary for its operation</td>
<td></td>
</tr>
<tr>
<td>boiler/loaded</td>
<td>entry</td>
<td>loading_boiler; score[10]</td>
<td>i//The boiler's furnace is being loaded with olive pomace, used as burning fuel</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-2. Excerpt from the FSM related to the operation of the boiler.
3.3.3 Game Objective and Tasks

The main goal of the game is to get the factory working by starting the steam power production and then operate the olive oil production machinery to actually produce a specific amount of olive oil. This goal aligns with the learning objective of the application, which is to learn how olive oil was produced in a steam-powered factory, in the middle of the previous century. This overlap of game and learning goals, or else providing game rewards (e.g., points for tasks performed) intrinsic to the learning objective (e.g., learning what tasks are involved in olive oil production), have been connected with increased motivation and learning gains (Garris et al., 2002; Lepper & Cordova, 1992).

The players begin in the main hall of the factory and have to attend to the alert messages that appear on the map, right at the outset of the game. They are led through the processes (either steam or olive oil production) through the alerts that appear at the bottom of the map or their own window, if they are close enough to the workstation involved (figure). They can move freely inside the virtual factory and have to visit the workstations in order to identify and troubleshoot each problem on a timely manner. In most cases an item/tool (or using their hand) is demanded to troubleshoot the problem, while in other situations the help of a second person with the right object is needed. In every case, the game provides feedback about the action performed on the right-side panel, inside the player’s window.

In total, there are fifty different tasks that need to be executed in the factory, using eight items/tools, and interacting with thirty different machinery/process parts. Many tasks are reoccurring to provide ample opportunities for interaction to all players (when multi-player interaction is used). There are twelve different types of workstations (mostly factory machinery like a steam engine, a boiler, mills, presses, and pumps) that players have to operate either individually or collaboratively. There are five distinct collaborative tasks, which two players have to execute synchronously by applying a tool on the same or different machine/factory parts (e.g., in Figure 3-7 Player 2 used a wrench to help Player 1 to attach a belt on a machine). Most tasks are repetitive to allow a different couple of players to execute them each time, and simulate real tasks that workers had to do in the factory, back in the old days. There are thirteen collaborative tasks in total, demanding three different types of interaction: selecting the same object with the same tool/item (e.g., lifting the heavy sacks full of olives with bare hands), selecting the same
object with different tools/items (e.g., lifting and placing a tank on a cart), or interacting with two different parts of the same machine (e.g., attaching a belt between two pulleys using a wrench, as is shown in Figure 3-7). When a collaborative action is executed the players involved are notified with a sound and an icon (‘Great Teamwork!’ as shown below).

![Figure 3-7. Task of attaching a belt collaboratively, before (left) and after (right) the task execution.](image)

This close collaboration between the players/learners demanded by C-OLiVE, where they have to share their understanding of the task at hand in order to effectively tackle the problem, is what we believe can promote greater learning between participants. This assumption is based not only on work being done in collaborative learning in general (as we have reviewed in Section 2.3), but even more by the affordances of physical co-presence for face-to-face interaction and negotiations of intents. As has been postulated by Vygotsky, children learn more effectively through their social interactions with a tutor or more knowledgeable peers (co-players in our case), by internalizing new knowledge through cooperative or collaborative dialogue (Vygotsky, 1978). These are two of the basic premises of orchestrated learning as used in this research, and our basic motivation for conducting the experiments described in the next Chapter; i.e., to investigate how facilitation and different levels of collaboration might impact learning.
Chapter 4

Small Group Interaction

We began our research by examining the first two research questions, which are focused on the impact of the level of interactivity or collaboration on learning and game experience. We decided to use three collocated participants to simulate small group interaction, as it is quite easy for a tripartite group to work together, while allowing us to observe and record their reactions and behaviors. In the first experiment, occurring in a controlled setting, we compared learning gains, using a pre/post-test design, between three conditions with varying levels of interaction with the VE and with each other. We also recorded the students’ subjective report on game experience, social presence, and sense of presence in the VE. The second experiment was identical to the first as the experimental design is concerned, but we changed the setting (an actual museum), the population (different cultural background), and substituted our passive condition (with a facilitated one). This was done in order to address our third research question.

In the following sections we report on these two completed experiments, providing details on our hypothesis, experimental design, procedure, participants, data analysis, and results. At the end of each section we discuss the most important findings from each experiment. Finally, we conducted a comparative analysis between the two studies and present our interpretation, along with some preliminary suggestions for building gaming CVEs for museum spaces.

4.1 Experiment I: Evaluating the effects of orchestrated, game-based learning in virtual environments for informal education

Previous research on serious games (Sasha A. Barab et al., 2012; Prensky, 2001a; Squire & Jenkins, 2003) and virtual environments (Dede, 1995; Roussos et al., 1999; Winn et al., 2002) indicated that such technologies can effectively harness contemporary learning practices (e.g.,
situated and experiential learning) to effectively engage and educate student audiences. However, the combination of these technologies and the opportunities they afford for social interactions of groups of students visiting informal learning spaces, such as museums and science centers, have not been adequately explored. Can a group of students interact meaningfully with a VE and get something out of it? Which is the optimal level of collaboration for engaging students, while also allowing them to make sense of the experience?

In this first study, we used our custom VE system (i.e., C-OLiVE, described in Section 3.3) to test multiuser interaction in different collaborative conditions. We have exploited the collocated collaborative nature of typical museum visits to enhance the system with important features of CVEs, like shared context, awareness of others, and negotiation and communication (Snowdon et al., 2000). The main goal of this study was to understand the impact of interactivity on learning and enjoyment in collocated collaborative game play. We wanted to move beyond the typical two-player setup and incorporate a third player, in order to increase the resemblance of the setting to group interaction, which is common in museum visits. The two main research questions we were trying to address are:

RQ1: What is the effect of the level of interactivity on learning in a gaming, collaborative VE (CVE) for more than two collocated participants?

RQ2: What is the interplay between level of interaction, game experience, social presence, and learning during within-group collaboration in physical space?

4.1.1 Hypotheses

Our hypothesis for RQ1 was that greater levels of interaction and collaboration would afford increased engagement and learning for all participating students (H1). This is based on previous research on CSCL (D. W. Johnson & Johnson, 2009; Qin, Johnson, & Johnson, 1995; Scardamalia & Bereiter, 1996), but also on the reported positive impact of collaboration on learning using games (Sasha A. Barab et al., 2012; Squire, 2005) and MUVEs (Dede, 2009; Ketelhut et al., 2007; Neulight et al., 2006). Besides learning gains, we hypothesize that the enhanced game experience and social presence deriving from the high interactive/collaborative condition will be a motivating factor that will positively affect learning outcomes (H2). This assumption is based on work being done on motivation and learning (Lepper & Cordova, 1992; Thomas W. Malone & Lepper, 1987),
as well as social game playing and motivation (Gajadhar, de Kort, & IJsselsteijn, 2009; Inkpen et al., 1999; Poels, van den Hoogen, Ijsselsteijn, & de Kort, 2012; Ravaja et al., 2006; Scott et al., 2003).

Our hypotheses are summarized in Figure 4-1, where we depict all the interrelationships between the controlled variable (interaction level) and the measured variables. Based on prior research, examples of which have been provided above, we defined the connections between the constructs, with the plus sign (+) indicating a positive correlation. E.g., we predict that the higher the interaction level (i.e., closer collaboration of the participants), the higher the social presence and presence felt by participants, and more positively perceived the game experience.

![Figure 4-1. The path model for validating RQ1 and RQ2; hypotheses are indicated using the lines, with the plus (+) sign indicating a positive correlation (e.g., interaction level will positively affect game experience).](image)

### 4.1.2 Experimental Design

Since interactivity was our main interest in this study, we used it as our between-subjects independent variable and designed three different levels. These had to do with the degree of involvement of the participants in the game and are the following: *auto*, where all the learners are watching a recording of someone playing the game; one-player (*IP*), where one player was controlling the game and the rest were helping her by indicating problems that needed attention or
suggesting plans of action; and three-player (3P), where all three players were interacting directly with the game (a graphical representation of the three conditions is displayed in Figure 4-2). The first setup is typical of existing museum guides for groups, where a curator or museum educator is controlling a digital exhibit, but we opted for a more controlled setup with no human intervention. In some cases one of the participants gets to acquire control, while the rest are indirectly participating, which resembles our second experimental condition. Both of these first two conditions have been used in other research evaluating informal learning for large groups, as an example (Sumners et al., 2012). Finally, the third condition is the one we hypothesize will afford greater learning benefits, due to increased engagement and social presence.

The three conditions of our experiment: Auto (left), 1-Player (middle), and 3-Player (right).

The main dependent variable was learning, while game experience and social presence were the secondary ones. Hence, we decided to administer a pre-test and a post-test and measure learning as the difference between the two scores. The test was a quiz about the content of the game (i.e., olive oil production in a steam-powered factory of the mid-19th century in Greece) and was divided into three parts. The first part (12 questions) asked general questions about factual information presented in the game; the second part (5 questions) assessed higher-level knowledge of the domain and demands that students combine information presented in the game and extrapolate their responses; and the last part (10 questions) evaluated their understanding of collaborative tasks performed in the factory.

To measure game experience, as a superset of engagement, we used the game experience questionnaire (GEQ), developed by the Game Experience Research Lab at the University of Eindhoven (Ijsselsteijn et al., 2007). The questionnaire is broken down into seven different

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30 The study material can be found in Appendix A.
dimensions that contribute, positively or negatively, to the game experience: immersion in the story (closely related to engagement; not to be confused with the attribute of the display technology), flow, challenge, competence, positive and negative feelings, and tension. A complementary questionnaire developed by the same research group, the social presence in gaming questionnaire (SPGQ) (de Kort & Ijsselsteijn, 2007), was used to capture the effect of the social context and interactions on the digital game experience. The SPGQ is measuring three main constructs contributing to social presence: empathy, negative emotions, and behavioral involvement. We found these appropriate self-report instruments for measuring game experience and social presence, as they were shown to be more sensitive to a broader range of emotions associated with digital game experiences and also provided a version specifically for kids. A more detailed rationale about our decision to employ these instruments and others that were considered, are presented in Section 2.4.2.

We used three questions for each one of the seven GEQ measures and a total of twelve questions from the SPGQ, all taken from the child versions of the questionnaires. Finally, we used the Slater, Usoh, Steed (SUS) questionnaire for assessing presence (Slater & Schroeder, 2000) (i.e., the feeling of ‘being’ inside the virtual factory). Although presence was not included in our research questions and our setup was not fully immersive, we still thought it would be interesting to measure presence to evaluate its effects on learning.

4.1.2.1 Participants

Our goal was to have a sample size of 54 students, based on an a priori power analysis (80%) for a medium effect of interaction level on learning. We eventually conducted a controlled study with 47 middle school students between 11 and 14 years old (M=12.25). We had more than twice as many males than females (33 boys, 14 girls). The distribution among conditions, which was randomly made based on pre-assigned groups, was the following: five groups (14 students) for the auto condition (one student did not show up), six groups (18 students) for the 1P condition, and five groups (15 students) for the 3P condition. Eventually, the study was conducted during a period of almost six months and students were recruited from two summer camps and two private schools from the area near the university.
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4.1.2.2 Apparatus

The game was projected on a large front-projected 16:9 wall display, and students were sitting at a distance of around 10ft (see Figure 4-3). A PC with an Intel Core i7 Extreme processor and a GeForce 7950 GT graphics card was used to run the application; we chose such a powerful setup in order to cope with the processing demands of rendering the environment three times, one for each individual viewpoint, in the 3P condition. Wireless Xbox controllers were used as interaction devices. The post-study questionnaires were administered online using iPads to enable automatic recording of responses.

![Figure 4-3. Experimental setup (controlled) of the 3P condition.](image)

4.1.2.3 Procedure

Student participants were approached through the managing entity, either the summer camp director or the class teacher, and parental permission was granted. The background survey and pre-test were administered online fifteen days prior to the experiment to avoid priming. Participants were instructed through a letter to their parents to complete the quiz to the best of their knowledge without any assistance from any source. During completion of all forms, students had to select a code name, which was used to identify their responses and match them with the game data, but also their real names in case we wanted to follow up on the study. On the day of the experiment,
groups of three students were initially informed about the goal of the study and watched a five-minute video explaining the main processes involved in steam and olive oil production. Next, they participated in a practice session to get used to the controls and the game interface. As soon as everyone felt comfortable (no time limit was imposed) they started the main trial.

Besides video recording each session (after obtaining verbal assent), a variety of time-stamped game data were recorded: actions attempted (errors) and performed, stations visited in the factory (using enter and exit triggers), full location log (every 0.5 seconds), machine state changes (both due to user interaction and timer events), score, and game duration. After the game was completed (again, no time limit was imposed and there was no way to lose), participants took the presence and game experience questionnaires, and then took the post-test (which was exactly the same as the pre-test). This order of survey administration was used to avoid recall of information from short-term memory. Participants in the auto condition, who watched a video of someone playing the game, did not complete the game experience or social presence questionnaires; neither did they have any game data being logged. Last, we conducted a short interview about participants’ experiences with the game.

4.1.3 Results

4.1.3.1 Effects of Interaction Level on Learning

In order to analyze the effect of our independent variable on learning, we conducted a mixed one-way ANOVA, where the time the test was taken was the within-subjects variable (pre- vs. post-test) and interaction level was the between-subjects variable (Auto vs. 1P vs. 3P). Participants in all three conditions revealed a highly significant gain in learning both overall and on each individual part of the test (p < 0.001), as can be seen in Figure 4-4 (all bars show std. error). However, there were no significant differences between the three conditions on the overall learning score. There was a significant effect of interaction level on learning for the last part of the quiz about collaborative tasks (F(2,44) = 3.465, p = 0.04). A Games-Howell multiple comparisons test revealed that students in the 3P condition demonstrated more learning on this section than the 1P ones (p = 0.036). This effect is diminished when only the non-controllers are taken into account for the 1P condition (F(2,38) = 2.82, p = 0.072), indicating that the controllers in the 1P condition had a poorer understanding of the collaborative tasks. This counterintuitive finding might be attributed to the added cognitive load needed for controlling the game.
Figure 4-4. Effects of interaction level on learning.

Although the level of control of the game was not an explicitly controlled independent variable in our study, we still deemed it interesting to investigate how the level of control predicts learning. Running an ANOVA with time of test as the repeated measures variable and degree of control as the between-subjects variable with three levels (no control, controlling alone, controlling with others) we found again no significant effects on learning, except for the final collaborative part, where score difference was significantly affected by control level ($F(2,44) = 3.529, p = 0.038, r = 0.27$). A post hoc Games-Howell test revealed that the difference was due to the players in the 3P condition who performed better than the ones who had no control whatsoever, either in the Auto or 1P conditions ($p = 0.044$). Although this appears to be a medium effect ($r \sim 0.30$), we should mention that the largely unequal sample sizes are a matter of concern for the reliability of post hoc tests, especially with the small sample size of 1P controllers ($N = 6$).

We also ran individual independent-samples t-tests for the 1P condition ($N = 18$) between the controllers ($N = 6$) and non-controllers ($N = 12$) and found no significant differences in learning. Additionally, we ran one-way ANOVA and post-hoc tests on each individual test question for a more fine-grained investigation of the effect of our independent variable on learning. We did not find any patterns that can help us draw useful conclusions, besides verifying that the 3P-condition participants had a better understanding of specific collaboration-related questions,
especially when compared to the 1P ones. A surprising finding was the significantly better learning of the Auto condition participants on one of the higher-level questions (i.e., “What might have caused the press tray to break?”) as compared to the 3P participants. In the discussion section below, we speculate on why the Auto condition might prove beneficial in some cases.

4.1.3.2 Effects of Interaction Level Game Experience

Scores on the GEQ and SPGQ were measured only for the interactive conditions on a scale of 1 (not at all) to 5 (extremely). Running a multivariate ANOVA on all seven measures, we found a significant effect of interaction level on GE using Pillai’s trace ($V = 0.47$, $F(7,25) = 3.13$, $p = 0.016$), which indicates that students in the 3P condition ($N = 15, M = 4.18, SD = 0.26$) enjoyed the game much more than their 1P counterparts ($N = 18, M = 3.78, SD = 0.65$). Also, running individual ANOVAs for these measures (Figure 4-5), we found a significant effect of interaction level on both positive ($p < 0.05$) and negative affect ($p < 0.001$), which reveals how the degree of interactivity affected the participants’ emotional state. For any GE measures where the assumption of the homogeneity of variance was violated, a Brown-Forsythe corrected F-statistic was used. None of the remaining game experience constructs was significantly affected by the treatment. Finally, there was no difference in presence score among the three conditions.

![Figure 4-5](image-url) Results for the individual GE measures.
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### 4.1.3.3 Effects of Interaction Level on Social Presence

Similarly to the GE analysis, we first ran a MANOVA with all three measures of SP, but found no significant effect of interaction level on social presence. However, the individual ANOVAs for each measure indicated significantly increased negative feelings for the 1P condition (Brown-Forsythe corrected $F = 5.58$, $p < 0.026$). This effect was diminished when only the non-controllers were taken into account, which is an interesting finding considering that we would expect these participants to be less satisfied than the ones controlling the game. To investigate this finding further, we compared the means of the participants split by the level of control (1P control or 3P control) and no control at all (i.e., the 1P non-controllers). The results shown in **Figure 4-6** reveal an apparent difference both in behavioral involvement and negative feelings. Although not statistically significant (only the uncorrected statistic of negative feelings is marginally significant at $p = 0.046$), the post hoc tests indicate significant differences between some of the three conditions. Specifically, a Tukey HSD test revealed a significant increase of behavioral involvement from 1P no control to 1P control ($p = 0.046$), and decrease of negative feelings from 1P to 3P control ($p = 0.42$); however, the largely unequal sample sizes make these tests untrustworthy.

![Figure 4-6. ANOVA results of SP measures by level of control.](image-url)
4.1.3.4 Effects of Interaction Level on Game Data

None of the logged game data seemed to have any effect on learning between conditions. However, actions performed on average were more than double in the 1P condition (M = 66.17, SD = 3.43) compared to 3P (M = 28.07, SD = 12.72), which was expected since tasks in 3P are distributed between players (corrected t-statistic due to inequality of variances t(1,17.9) = 10.67, p < 0.001). Trying to do an action at the wrong time was considered an error, except when collaborative action was required, since players were often clicking repeatedly to achieve the right synchronization. Errors made were not found to be significantly different among conditions, but the distribution of errors was much larger in the 3P condition (1P: min = 31, max = 96; 3P: min = 11, max = 324), as can be seen in Figure 4-7a. This can be explained by the different levels of involvement players assumed either due to their game-playing experience and style or fear of making mistakes.

![Figure 4-7](image)

Figure 4-7. (a) Errors and (b) time of first action per condition.

We also noticed from our observations that participants in the 3P condition had trouble figuring out how to troubleshoot the first problem (i.e., either starting up the boiler or attaching a belt to one of the machines). Indeed, students working together took significantly more to carry out the first task compared to the 1P condition (t(1,31) = -7.18, p < 0.001), as can be seen in Figure 4-7b. This is probably an indication of the overhead that collaboration entails, demanding more effort to
establish effective communication. However, this extra time for the 3P group did not seem to affect the overall completion time (1P: M = 36mins 52secs; 3P: M = 38mins 57secs).

4.1.3.5 Path Analysis

In an attempt to explore the combined effect of the independent variable (interaction level) and the self-reported measures (game experience, presence, social presence) to predict the outcome (learning), we decided to use the partial least squares (PLS) statistical analysis method. PLS is comprised of a structural model with the relationships between the latent constructs (blue circles) and a structural equation model with the predictive relationships between each latent construct and its associated observed indicators (yellow boxes) (Fair, Ringle, & Sarstedt, 2011). We used SmartPLS\(^1\) to setup and test the path model we constructed based on our hypotheses. Figure 4-8 shows the model and the results of the analysis using the same number of cases (N=47) and bootstrapping with 5K samples.

Figure 4-8. Path model with hypotheses (+ sign indicates positive correlation) and results (lines): solid lines are 5% significant; thick lines are 1% significant; dotted lines are not significant.

\(^{1}\) More information at: [https://www.smartpls.com/](https://www.smartpls.com/)
Using this model, interaction level significantly predicted learning in the presence of the other constructs ($t = 2.24, p < 0.05$), with higher levels of interactivity predicted to produce greater learning. Interaction level also significantly predicted social presence ($t = 2.06, p < 0.05$), but not game experience or presence. Interestingly enough, this model shows that social presence had a highly significant effect not only on game experience but also on learning. These results support our hypotheses about the positive impact of collocated gameplay and collaboration on game experience and eventually learning.

### 4.1.4 Discussion

Although the main analysis was not able to reject the null hypothesis, the path analysis did support the combined effect of all the constructs (interaction level, game experience, and social presence) on learning. This result is also supported by research on the impact of increased social presence on enjoyment (Gajadhar et al., 2008), which has been shown to positively affect learning (Thomas W. Malone & Lepper, 1987). This cascade effect of the attributes of collaborative serious games and VEs on learning has been the main premise of our research.

Furthermore, there were many interesting findings that point towards the benefits of collocated collaboration on the overall game experience. Besides the statistical findings, our qualitative results from observations, recordings, and interviews indicate that students enjoyed the 3P condition much more than the other two. There were many cases in the 1P condition where both controllers and non-controllers expressed their preference to engage in a multi-player game. Despite the fact that this was not captured in all our individual GE measures, comparing GE as the mean of all seven measures did reveal a significant difference between conditions.

Increased fun can also be attributed to the simultaneous (or orchestrated) nature of collaboration we have employed in C-OLiVE. The results of comparing controllers in both conditions with 1P non-controllers (Figure 4-6) indicated a higher interconnectedness felt by the students with control (i.e., behavioral involvement), but also more negative feelings on behalf of the ones with 1P control when compared with 3P players. Although the comparison between 1P controllers and non-controllers did not prove to be significant, it is still interesting to note that 1P controllers felt worse. This can be justified by the pressure that these students felt by having the fate of the game in their hands, especially if they were not experienced players, as observed during game play but also relayed through the interviews.
In alignment with our finding about the increased time to complete the first task, we have noticed students struggling to establish effective communication during the beginning of the 3P game. Counting also the interventions we had to do in this condition (our policy was to provide a hint from the video if they were stuck for three minutes), the 3P condition demanded more than twice the number of interventions on average compared to 1P (4.6 vs. 2.0). Although this did not seem to negatively affect the game experience of students or the learning achieved in this condition, it does indicate that multiuser social interactions demand greater effort in communicating intent, until commitment demands are revealed to and understood by participants (B. Brown & Bell, 2004).

Despite our effort to conduct as thorough a study as possible, there are some limitations of our experimental design. First, the sample size was small and may not be easily generalizable to a wider population. Second, comparing controllers and non-controllers statistically did not have adequate power, as the sample sizes were largely unequal. Third, the experimental setting was not ecologically valid for the purpose of this research, since it was mainly conducted within controlled conditions. Fourth, the interaction design of C-OLiVE was noticed to be different than commercial games (especially the navigation controls), as commented by some students. Finally, the scientific domain chosen, the collaborative interactions it affords, and the design of these interactions impose some constraints to the overall instructional design; thus, we should be cautious in generalizing these findings.

4.2 Experiment II: Small Group Learning with Games in Museums: Effects of Interactivity as Mediated by Cultural Differences

Having found an association of learning with increased collaboration in our first controlled study, we wanted to further research the degree to which these findings can be generalized in a more ecological setting. Thus, our next step included running the same experiment in a museum, in order to investigate how the motivations and expectations of a museum visit, but also the prior knowledge and interests of the visitors, might affect learning (John H. Falk & Dierking, 2000). Thus, we ran the study in a museum in Greece, a place with rich cultural history in olive oil production, and consequently anticipated greater prior knowledge on behalf of the students. Moreover, this allowed us to test our hypotheses in an ecologically valid setting, with a much larger sample size that will increase the power and generalizability of the results.
Furthermore, the impact of facilitation on learning has not been adequately researched, especially inside informal learning contexts. There is quite a debate about the effectiveness of constructivist and discovery learning approaches (Kirschner et al., 2006), especially for serious games (Clark, 2007; Druckman, 1995; B. Sawyer, 2005). However, there has not been enough research so far to examine how information presentation using a gaming VE can be affected by expert facilitation as compared to free multiuser game playing, inside a museum context. Consequently, we decided to replace the non-interactive condition (Auto) that proved less effective in our first experiment, with one where the game is played live by an expert guide, who also offers additional information and prompts users to participate by asking questions. Thus, in this second study, besides the first two research questions addressed before, we also added a third one:

RQ3: What is the effect of culture, prior knowledge, and the style of information presentation (facilitated or not) on learning using a gaming CVE in a museum-type setting?

4.2.1 Hypotheses

Our hypotheses for the first two research questions were the same as in the first study (see Section 4.1.1 and Figure 4-1), since our assumptions were partly validated (see Figure 4-8). Moreover, in this study we hypothesize that prior knowledge will have a beneficial impact on the learning outcome (Roschelle, 1997), assuming that Greek students will have an—even slightly—more complete mental model of the domain knowledge and no significant misconceptions (H3a). Similarly, students who have been—culturally—exposed to the subject more often will probably have a greater interest and motivation to learn more by playing the game (Csikszentmihalyi & Hermanson, 1999; John H. Falk & Dierking, 2000), leading to greater learning gains.

Nonetheless, cultural differences might also affect the preferred way of information assimilation, since the sociocultural background affects learning styles (Guild, 1994; Pinkard, 2004; Shade, 1989), which can have unpredictable effects on learning (H3b). However, we do not anticipate any influence of cultural differences on perceived enjoyment and sense of social presence (H3c). Children are social beings who greatly enjoy playing with friends (Inkpen et al., 1999; Shaffer, Squire, Halverson, & Gee, 2005) and we believe this applies across cultures, although not enough studies have been conducted so far to verify this claim. Our study might be one of the first ones to actually assess learning through children’s collaboration with a gaming MUVE across cultures.
Finally, facilitation is generally believed to help students construct meaning and scaffold their cognitive processing (John H. Falk & Dierking, 2000; Kirschner et al., 2006). On the other hand, increased scaffolding has been shown to impede informal behaviors (i.e., experimentation and self-generated questions), an effect that can be mitigated by encouraging group collaboration (Yoon et al., 2013). In our study, we hypothesized that facilitation can be beneficial mainly for students with some learning difficulties (H3d), as prior research with MUVEs using performance-based measures has revealed (Dede, 2009; Ketelhut et al., 2007). We decided to use facilitation only for our passive condition, resembling the typical setup of classroom visits to museums, leaving our other two conditions with largely unconstrained interaction and minimal guidance (unless students had trouble progressing in the game for an extended period).

4.2.2 Experimental Design

Interactivity was used as a between-subjects independent variable with three different levels. These levels, in ascending order of the degree of involvement of the participants in the game, were: facilitated, where a museum educator plays the game and provides information and prompts as an incentive for students to participate; one-player (1P), where one player controls the game and the rest are helping him by indicating problems that need attention or suggesting plans of action; and three-player (3P), where all three players interact directly with the game. The first setup is typical of existing museum guides for groups; the second resembles situations where someone controls a digital exhibit and others are watching, intervening at times; and the third is the one we hypothesize will afford an improved game experience and greater learning benefits, according to our findings from the previous study.

The main dependent variable was learning, while game experience (GE) and social presence (SP) were secondary ones. Perceived knowledge of and interest in the domain, as well as expectations from the visit being met were also measured on a five-point scale. Learning was measured as the score difference between a pre-test and a post-test. This was a quiz about the content of the game and was divided into three parts. The first part (12 questions) asked about factual information presented in the game; the second part (5 questions) assessed conceptual knowledge of the domain, requiring students to combine information presented in the game; and the last part (10 questions) evaluated their understanding of collaborative tasks performed in the
factory. Similar to our previous study\(^{32}\), we used subsets of the Game Experience (GEQ) and Social Presence (SPGQ) questionnaires, developed by the Game Experience Research Lab at the University of Eindhoven (de Kort & Ijsselsteijn, 2007; Ijsselsteijn et al., 2007), to measure these two constructs.

### 4.2.2.1 Participants

Our goal was to have a sample size of at least 111 students, based on an \textit{a priori} power analysis (80\%) for a small effect of interaction level on learning \((d = 0.15)\), deriving from our first study. We eventually had 156 students between 10 and 14 years old \((M = 11.7)\). We had an almost equal distribution of males and females \((85 \text{ boys}, 71 \text{ girls})\). The distribution among conditions was as follows: seventeen groups \((51 \text{ students})\) for each one of the 1P and 3P conditions and eighteen groups \((54 \text{ students})\) for the facilitated condition. The study was conducted during a period of one month at the Nikos Kazantzakis Museum (NKM) in Crete, the largest island of Greece with a rich olive oil production history, with students recruited from elementary and middle schools\(^{33}\) of the county of Heraklion. Although we attempted to recruit students equally across grades, the time of study \((May 2014)\) was prohibitive for middle school field trips due to scheduled exams; consequently, we had only one middle school class \((21 \text{ students})\).

### 4.2.2.2 Apparatus

The game was projected on a large front-projected 16:9 wall display, and students sat at a distance of around 3 meters \((see \textbf{Figure 4-9})\). In order to serve a larger number of groups, two workstations were set up in the museum in dedicated spaces, in order to avoid interference with the museum’s normal operation. We used two laptop computers: an HP Pavilion with Intel Core Duo processor and a GeForce GT 9600M graphics card for the facilitated and 1P conditions, and a Lenovo with Intel i7 processor and a GeForce GT 750M graphics card for the 3P condition. Wireless Xbox controllers were used as interaction devices in all conditions. The post-study questionnaires were administered using iPads to enable automatic recording of responses.

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\(^{32}\) The study material were translations of the original ones, both of which can be found in Appendix A.

\(^{33}\) Elementary students in Greece are usually aged 7-12 years old \((6 \text{ grades})\) and middle school 13-15 \((3 \text{ grades})\).
4.2.2.3 Procedure

School class visits were arranged by the museum ahead of time from both rural and urban districts, in order to have a wider distribution of domain prior knowledge level. After entering one of the study venues, classes were introduced to the study objective. Next, they completed a background survey and took the pre-test using pencil and paper (we found no effect of priming in our previous study for subjects completing the pre-test just before the game). Students selected a code name, which was used to identify their responses on all forms and match them with the game data. The class then watched a five-minute video explaining the main processes involved in steam and olive oil production. Next, the class was split into groups of three with the assistance of the leading teacher; an attempt to have mixed-gender groups was made, but we mostly allowed free group formation as a means to let students experience the game with friends. Then, the first two groups went into the study rooms and started with a practice session to get used to the controls (for the interactive conditions) and the game interface. As soon as everyone felt comfortable (no time limit was imposed) they started the main trial.

Students in the interactive condition primarily played by themselves, but guiding tips were provided if they were stuck at the same problem for more than one minute. Their interactions (e.g., negotiation, common action, disagreement, etc.) were observed and recorded on a specially designed sheet. Also, a variety of time-stamped game data were recorded: actions attempted
(errors) and tasks performed, stations visited in the factory, full location log (every 0.5 seconds), machine state changes, total score, and game duration. After the game was completed (a flexible limit of one hour was imposed in order to enable participation for most students), participants took the game experience questionnaire and then the post-test (exactly the same as the pre-test). This order avoided information recall from short-term memory. Last, students were thanked for their participation and awarded a certificate with their game achievements as a group.

4.2.3 Results

All but two groups finished the game, both in the 3P condition; one due to the students’ inability to advance adequately in the game after an hour, and the second due to simulator sickness experienced by one of the participants. Since their post-test scores did not divert considerably from the mean we decided to include them in the analysis; however, we excluded their logged game data. Initially, we ran some exploratory statistics to look for outliers and missing values. Extreme values (more than three standard deviations away from the mean) in the game experience questions were substituted with the rounded mean of that question, per condition. Throughout our main analysis presented below, we made sure that the statistical models used satisfied the necessary assumptions and corrected values are reported whenever these assumptions were violated.

4.2.3.1 Correlations

We started by exploring bivariate correlations between the data and found that interaction level was negatively correlated with learning gain ($r = -0.197$, $p = 0.014$), which is further explored below. Tension ($r = -0.194$, $p = 0.015$) and negative feelings ($r = -0.241$, $p = 0.001$) were both negatively correlated with learning, indicating that students’ lower score improvement was affected by their increased tension and negative feelings caused by collaboration (i.e., shyness, shame, jealousy). Challenge ($r = 0.260$, $p = 0.001$) and behavioral involvement ($r = 0.334$, $p < 0.001$) were both highly correlated with interaction level, as expected by the increased demands of the interactive conditions to work together and stay connected in order to finish the game. Learning was significantly correlated with the student's age and grade, with older students revealing a significantly better score improvement ($r = 0.240$, $p = 0.003$). Finally, interaction level was highly correlated with gender ($r = -0.214$, $p = 0.007$), with boys participating more in interactive conditions, an unwanted effect caused by letting teachers decide on group formation and participation order.
4.2.3.2 Effect of Interaction Level on Learning [RQ1]

Running a one-way mixed ANOVA with the time the test was taken (before and after the intervention) as the within-subjects variable, and interaction level (Facilitated, 1P, and 3P) the between-subjects variable, we found a highly significant effect of the time the quiz is taken on the score, $F(1,153) = 579.03, p < 0.001$, indicating that overall, students performed significantly better on the post-test compared to the pre-test (Figure 4-10; all bars show std. error). We also found a significant interaction between time and interaction level on the score, $F(2,153) = 3.15, p = 0.046$). A Tukey HSD post-hoc test revealed a significant improvement in score performance in the Facilitated condition as compared to the 3P condition ($M_{dif} = 7.9, p = 0.038$). Analyzing each quiz part separately, we found that the Facilitated condition students improved their score significantly more than the 3P participants on the first quiz part with factual information ($M_{dif} = 6.62, p = 0.008$), and more than the 1P participants on the last quiz part about collaborative tasks ($M_{dif} = 2.14, p = 0.016$); there were no differences between groups on the second part (conceptual knowledge).

![Figure 4-10](image-url) Figure 4-10. Effects of interaction level on learning (F=Facilitated).
4.2.3.3 Effects of Interaction Level on GE and SP [RQ2]

The interaction level had a highly significant effect on the challenge experienced by the students according to an ANOVA, $F(2,153) = 7.15, p = 0.001, \omega = 0.27$, with both interactive conditions being significantly more challenging than the Facilitated condition, as revealed by a Games-Howell post-hoc test (Facilitated vs 1P: $p = 0.008$; Facilitated vs 3P: $p = 0.002$). Interestingly enough, both interactive conditions were found equally challenging by participating students ($p = 0.99$). Tension was also found to be significantly affected by the interaction level, $F(2,153) = 3.295, p = 0.04, \omega = 0.17$. A Games-Howell post-hoc test indicated that the students participating in the 1P condition felt more tense than their Facilitated counterparts ($p = 0.041$), while there was no difference between the Facilitated group and 3P participants. Interaction level had a highly significant effect on positive affect, $F(2,53) = 5.786, p = 0.004, \omega = 0.24$. A Games-Howell post-hoc test revealed that the students participating in the 3P condition had significantly better feelings compared to their 1P counterparts ($p = 0.015$), whereas there was no significant difference found between 3P and Facilitated students ($p = 0.067$). Interaction level had also a highly significant effect on negative affect, $F(2,153) = 7.71, p = 0.001, \omega = 0.28$. A Games-Howell post-hoc test revealed that the negative feelings were less for students participating in the Facilitated condition, as compared to the 1P ($p = 0.002$) and 3P conditions ($p = 0.001$).

For the SP measures, the interaction level had a highly significant effect on the behavioral involvement of the students, $F(2,153) = 11.24, p < 0.001, \omega = 0.34$. A Bonferroni post-hoc test showed that the interactive conditions elicited a significantly higher involvement from the participating students (1P vs. Facilitated: $p < 0.001$; 3P vs. Facilitated: $p = 0.001$). Social presence overall (as a mean of the three constructs) was also significantly affected by the interaction level, $F(2,153) = 5.121, p = 0.007, \omega = 0.22$. A Bonferroni post-hoc test showed that the 3P interactive condition elicited greater feelings of being together with a peer as compared with the Facilitated one ($p = 0.008$), whereas no significant difference was found between the 1P and Facilitated condition participants ($p = 0.067$).

4.2.3.4 Effects of Non-Game Elements on Learning [RQ3]

Besides the scores from the pre/post-test and the post-experience questionnaire, students also self-reported on their expectations from the museum visit (no specific information were given by teachers ahead of time) and their perceived prior knowledge and interest on olive oil production.
Motivation and Expectations

The basic motivation of visiting the museum (learn about olive oil production, play a fun game, or enjoy the museum) was not found to be correlated with learning gains, nor pre/post-test scores, by running an ANOVA. On the other hand, the expectations of students and their perception of the information they learned as interesting or useful were correlated with social presence and game experience, as well as most of the comprising latent measures (Table 4-1). More specifically, students whose expectations were met and found the information both interesting and useful, were the ones who expressed higher empathy for their peers and felt more immersed in the game story, greater flow, and positive affect, but less negative affect and tension. However, expectations being met or not, and perceived interest/usefulness of the content, were not correlated with learning gains.

<table>
<thead>
<tr>
<th></th>
<th>Visit went as expected</th>
<th>What I learned was interesting</th>
<th>I found the information useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersion</td>
<td>.258**</td>
<td>.481**</td>
<td>.435**</td>
</tr>
<tr>
<td>Competence</td>
<td>.227**</td>
<td>.286**</td>
<td>.424**</td>
</tr>
<tr>
<td>Flow</td>
<td>.194*</td>
<td>.328**</td>
<td>.283**</td>
</tr>
<tr>
<td>Positive Affect</td>
<td>.225**</td>
<td>.383**</td>
<td>.410**</td>
</tr>
<tr>
<td>Challenge</td>
<td>.115</td>
<td>.163</td>
<td>.047</td>
</tr>
<tr>
<td>Negative Affect</td>
<td>-.281**</td>
<td>-.286**</td>
<td>-.240**</td>
</tr>
<tr>
<td>Tension</td>
<td>-.200*</td>
<td>-.123</td>
<td>-.179*</td>
</tr>
<tr>
<td>GE</td>
<td>.336**</td>
<td>.470**</td>
<td>.458**</td>
</tr>
<tr>
<td>Empathy</td>
<td>.322**</td>
<td>.313**</td>
<td>.313**</td>
</tr>
<tr>
<td>Behavioral involvement</td>
<td>.158*</td>
<td>.149</td>
<td>.085</td>
</tr>
<tr>
<td>Negative feelings</td>
<td>-.048</td>
<td>.060</td>
<td>.039</td>
</tr>
<tr>
<td>SP</td>
<td>.284**</td>
<td>.242**</td>
<td>.198**</td>
</tr>
</tbody>
</table>

*significant at 5%    **significant at 1%

Table 4-1. Correlations of museum visit perception and GE-SP measures.

Perceived Prior Knowledge and Interest

Students who expressed greater interest in olive oil production and thought they knew more about the subject revealed lower learning gains. Both interest in the subject ($r = -0.166$, $p = 0.039$) and perceived knowledge of the subject ($r = -0.207$, $p = 0.009$) were negatively correlated with learning. As expected, interest in and perceived knowledge of the subject were highly correlated
(r = 0.523, p < 0.001). By plotting the pre- and post-test scores along with their difference (Figure 4-11), it is clear that students who thought they did not know anything about olive oil production (N = 26) did have lower pre-test scores (M = 5.04) but also had among the highest post-test scores (M = 39.44) and the highest level of learning gains (M = 34.40). On the other hand, the few students who thought they were rather knowledgeable about the subject domain (N = 10 for “Very well” and “Perfectly”), scored higher on the pre-test, but had among the lowest post-test scores, leading to the two lowest amounts of learning among the five levels of perceived knowledge.

![Figure 4-11. Test scores by perceived prior knowledge.](image)

### 4.2.4 Comparing Studies across Cultures

Also relating to our RQ3 Comparing our prior study [3] with the current one, we conducted a two-way independent ANOVA with study venue and interaction level as the independent variables. We coded the first interaction level as "Passive" (including Auto from the first study and Facilitated from this study) and kept the other two levels as 1P and 3P, since they were identical in both studies. We found a significant main effect of study venue on the score difference between pre- and post-test, F(1,197) = 12.64, p < 0.001. More specifically, students participating in the first
study had significantly higher learning gains (M = 41.32, SD = 16.58) than students in the museum study (M = 32.60, SD = 19.22). The difference is even more prominent when comparing the score difference of the 3P condition between the two study venues, with the first study 3P students scoring the highest out of the three conditions (M = 45.30, SD = 15.50) and their second study counterparts scoring the lowest (M = 27.93, SD = 15.83). There was no significant effect of interaction level on score difference (p = 0.27). There was also no significant interaction between the study venue and the interaction level on the score difference (p = 0.2). Nonetheless, the interaction plot (Figure 4-12) indicates that scores are very different for the 3P condition among studies. This was verified by running a simple effects analysis, which revealed this was a significant effect for this condition (p = 0.001).

![Figure 4-12. Effects of study x interaction level on learning.](image)

4.2.4.1 Prior Knowledge

Despite our assumption that students in Greece would have greater prior knowledge in the domain, the pre-test scores did not verify this. Students in the US scored significantly higher on the pre-test than the ones in Greece, F(1,197) = 4.68, p = 0.032. However, considering the pre-test as the only measure of prior knowledge is not accurate, as the questions were specific to the production process followed in a steam-powered factory of the last century. Moreover, students in the museum
study were repeatedly instructed not to guess, whereas no such control could be exerted in the first study where students took the pre-test online. We can, however, assert that some Greek students had greater exposure to the domain, according to perceived prior knowledge and the number of students who had visited an olive oil factory with school and/or family (N = 111). Students who had visited a factory with both family and school did score significantly higher on the pre-test compared to the ones who had never had any exposure (Bonferroni \(M_{\text{dif}} = 10.18, p = 0.022\)), but this was not reflected in either the post-test nor the pre/post-test score difference.

4.2.4.2 Cognitive Skills, Culture, and Learning Context

Findings related to the effects of cultural differences, cognitive skills, and setting on GE, SP, and learning are mainly qualitative, deriving from our observations and discussions with teachers. Although we intentionally chose the same age group (11-13 years) in both studies, it appears that the two populations were not of the same cognitive development stage. This was manifested in the museum study with reading difficulties during both test taking and game play, a number of unknown words (poor vocabulary), decreased attention and focus to the on-screen instructions, and minimal recorded instances of recalling information from the introductory video (as many teachers also attested). Cognitive differences also had an impact on game completion time. Students playing the interactive conditions in the first study finished the game significantly faster than the museum study students, \(F(1,79) = 13.90, p < 0.001\); 1P students were faster by 8.2 minutes, while 3P students finished 14.6 minutes sooner.

We observed several important differences between the two studies that can be attributed to culture and the learning context. 1P participants in the second study were more democratic about who would get the control and did not always follow our random assignment, surrendering the controller to a peer six times (35% of all groups), as compared to none in the first study. Also, students controlling the game in the second study were more receptive of their peers’ instructions, seemed to lack initiative, and rarely showed dominant or arrogant behavior, unless they had a problem cooperating. In many cases, students revealed a sense of solidarity either by loudly guiding their peers or whispering the response to a peer when asked by the facilitator; this is confirmed by a significantly higher sense of empathy in the second study for the interactive conditions, \(F(1,133) = 4.93, p = 0.028\). Overall, students in the second study seemed to care much more about the score, monitoring their points, and asking the observer if they did better than other
groups; a competitive behavior not observed in the first study. Finally, gender seemed to have a greater effect on social behavior in the second study, where girls were observed in many cases to be less involved in the game and less competitive with their peers and other groups.

4.2.5 Discussion

There was a strong indication in the current study that for the specific sample of students with observed reading and cognitive difficulties, facilitation by an expert guide helps in understanding and assimilating the complex information provided during this discovery learning game, as has been shown by prior research with MUVEs (Ketelhut et al., 2007). In responding to the factual information questions, Facilitated students scored better, and, with the prompts of the facilitator, had a better understanding of the material presented. On the other hand, 3P students were likely overwhelmed by the overhead of game play and social interaction, as a result of which they learned less factual information. Moreover, Facilitated students had a better understanding than 1P students about which actions were collaborative. This can probably be attributed to the fact that 1P non-controllers were occupied with the alert messages and guiding the controller, as a result of which they missed the indicators of collaborative actions. This is also supported by the fact that 1P controllers performed better than 1P non-controllers on this part of the quiz.

Adding interactivity increased challenge, which has been shown to promote learning in some situations (T.W. Malone, 1981). However, if challenge is far above the student’s competence level, this causes anxiety (J. Chen, 2007) and can hinder learning. Indeed, we found tension to be negatively correlated with learning but also affected by the interaction level, with 1P participants feeling tenser than both other conditions. This explains the stress observed in both controllers and non-controllers in this condition; the former for coping with the controls and demands of the game, and the latter for frustration caused by lack of agency in the game. This is in accordance with the increased negative affect and decreased positive affect experienced by the 1P participants, as compared to the other two conditions. 3P students also expressed more negative affect, which can be justified by the increased challenge that most 3P groups experienced during gameplay due to the cognitive difficulties mentioned before.
4.3 General Discussion of Experiments I & II

Our results show that students in the museum study had difficulty coping with the game, affecting their learning. It seems that the game format and the discovery type of learning were incompatible with the students’ learning style. Students in our first study came from private schools in a university town where technology-based learning opportunities abound, while the second study recruited students from public schools of a Greek island with limited exposure to discovery-based learning. As a result, the increased cognitive load required to play the game overloaded students’ working memory to the detriment of learning (Sweller, 1994). We also know that cognitive engagement or mental effort invested in a task is determined by the way information is perceived by the student (i.e., the culture-specific cognitive style) and eventually influences the learning process (Shade, 1989). Considering the different cultures and also the fact that we chose populations of the same age, instead of school grade, indicates that what is important in designing instructional tools for any context is the cultural, rather than the biological, age of learners (Vygotsky, 1986).

The adverse effects of prior domain knowledge on learning can possibly be explained by the discrepancy between the students’ knowledge of contemporary olive oil production and the historical process that was presented in the game. Such a disparity can interfere with learning, as learners tend to interpret new information in a way that agrees with already established knowledge (Roschelle & Teasley, 1995). Furthermore, prior knowledge appears at many other levels of learning, like perception, conception, attention, procedural skills, and reasoning, and affects how students interpret instruction, often leading to incorrect interpretations. Hence, we argue that the students of the second study performed poorly in the interactive conditions, but also benefited the most by facilitation, because they did not have the skills for discovery learning. The guided discovery offered in the Facilitated condition eased the selection, organization, and integration of information through the guide’s explanations (Sweller, 1994).

The observation that museum study students seemed more focused on score might be attributed to a setting effect, since students, being on a field trip, were in “play mode” before and after the experiment. This difference in “leading motive orientation” (i.e., learn vs. play) can largely account for learning outcomes in social situations and educational settings (Hedegaard & Fleer, 2013). Additionally, students in the museum study seemed more performance-oriented,
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seeking extrinsic rewards like high scores, while first study students seemed more mastery-oriented, pursuing personal pride and pleasure by mastering the game. This disparity in goal orientation and its proven impact on learning (Dweck & Leggett, 1988) might also be attributed to cultural differences. We suggest that the large difference of the two cultures in the individualism dimension (IDV) of Hofstede’s theory of cultural dimensions (Hofstede et al., 2010) explains how Greek students (IDV = 35) derived self-respect through in-group social acceptance, as compared to individual self-actualization stemming from acquiring mastery for the US students (IDV = 91).

The fact that Greece is largely a collectivist culture can also account for the fact that students seemed more concerned with their in-group relationships and equal collaboration opportunities. As an example, one student in the 1P condition surrendered control to a lower-ability student after finishing the practice, in order to boost his peer’s low self-confidence (as attested by their teacher). The fact that this was eventually detrimental to the game experience (as the second student struggled to cope with the game’s demands) and learning gains was undervalued by the group.

4.4 Limitations of Experiments

We acknowledge that this was a complex set of studies, inherently introducing some limitations. The assessment type used (pre/post-test scores) largely ignores the rich type of learning (diverting from the conventional absorption-transfer model) happening with MUVEs (Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005; Ketelhut et al., 2007) and especially inside museums, where learning becomes concrete with future experiences (John H. Falk & Dierking, 2000). To understand the complex learning happening outside school we need to research learning across domains and social experiences (Sefton-Green, 2004). However, this study was an intermediate step to evaluate game-based, collocated collaborative learning and not a pure museum-based learning experience. Future studies will be designed to include a more qualitative evaluation approach with follow-up assessments.

Teachers were intentionally not instructed to give specific prior information about the visit, which might be a confound concerning differing student expectations. A specific activity in class prior to the visit could be a remedy for this, although in this study we deliberately left this variable uncontrolled to assess students’ inherent interest and motivation. Also, there were many differences between the two studies (e.g., venue, pre-test time/place, varying time interval between
video and game, etc.) making it difficult to determine which of them might account for differences in the results. Ideally, we should have run individual experiments controlling one or two of these variables, in order to acquire a better insight about their effects on the overall experience and learning outcome.

Finally, cognitive level and culture cannot be dissociated, but we should optimally strive to get samples from populations with equal cognitive and perceptual skills, maybe by using some measure of cognitive ability. Similarly, prior knowledge was not controlled, making the assumption that Greek students will have greater exposure to the domain due to a long tradition in olive oil production. Although we do have some evidence of this hypothesis from student responses, in future work we will assess prior knowledge \textit{a priori} to make sure that samples come from two different populations. Finally, the largely unequal sample sizes between the two studies ($N_1 = 47$ vs. $N_2 = 156$) render comparisons less accurate, but we still get valuable indications of which factors contribute to the differences found.

## 4.5 Conclusions

Although we understand that this was a set of preliminary studies and more data are needed to support our hypothesis, we still believe that the findings point towards some interesting direction for gaming CVEs design for museum learning. More specifically, we suggest that such informal learning approaches can greatly benefit from following some key guidelines:

\begin{enumerate}
\item \textbf{Enable simultaneous collaboration of visitors only when learners have been accustomed to discovery learning experiences}

Multi-player experiences can be beneficial by means of increased engagement, positive feelings, and player interconnectedness, if they are not overly challenging for the participants’ cognitive and perceptual abilities.

\item \textbf{Adapt to individual student skills and preferences}

Accommodate different learning styles by adjusting difficulty level (e.g., text, amount, and nature of tasks according to age and reading skills), by providing contextual information and instruction on demand, and by allowing participants to choose freely the degree of involvement in the activities.
\end{enumerate}
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iii. Use scaffolding to alleviate the burden of working in a complex learning environment, especially for novice or less able students

Start with easier problems including guidance, if possible, and gradually increase the level of difficulty by also removing learning aids (fading). This will relieve students from unnecessary frustration, increasing engagement, and give them enough time to adapt to the increased complexity of the interactive learning environment.

iv. Precede the game with some sort of structured activity in order to remedy misconceptions that might arise from prior knowledge

Present an in-school activity in a similar format that will introduce the subject to students (e.g., explain the context of olive oil production and the machines used, so that everyone knows what a pump or a belt does), since ignoring basic knowledge or having a false conceptual model interferes with the actual learning objectives.

v. Follow the museum experience by some conclusive information presentation

Display the introductory video not only at the beginning, where information might seem overwhelming and irrelevant, but also at the end, in order to provide responses to the questions generated by students during the discovery process.

Learning tools need to be culturally informed if we are to credibly attribute learning outcomes to students; otherwise we simply ignore how our “culturally disconnected learning tools” are affecting these outcomes (Pinkard, 2004). Our work so far is a contribution towards this goal. More systematic and rigorous research effort is demanded, if we are to develop interactive experiences for student groups visiting museums that respect and harness cultural idiosyncrasies, in order to create and sustain meaningful learning.
Chapter 5

Audience Interaction

Our work so far included two experiments with middle school students, using a custom gaming VE for three players, either in a controlled environment or inside a museum space. We assessed the impact of different levels of interaction, or collaboration, as well as facilitation of a passive condition on learning, game experience, and social presence. Our findings were contradictory so far, with results from the first study revealing an association of the simultaneous (orchestrated) interaction of students with increased learning gains, while results from the second study indicating a learning benefit for the students in the—more passive—facilitated condition. Results about game experience and social presence are comparable, with the full collaborative condition (i.e., all the students have immediate control of the game) revealing the highest positive measures (e.g., positive affect and behavioral involvement) and the middle collaborative condition (i.e., only one player controls the game) revealing the highest negative measures (e.g., tension and negative affect). The effect of culture and prior knowledge has also been investigated and discussed in the light of sociocultural and learning theories.

These results signify that more research is needed in the domain, in order to identify how learning and game experience are affected during small group interaction with gaming VEIs for informal learning. However, our goal here is not to understand the intricacies of collaborative problem solving, which has been addressed in other studies focused on collaborative learning (Barron, 2003), but rather to explore the potential of large group interaction in museum spaces. Hence, our next step was to scale up our interaction paradigm, to accommodate for the simultaneous interaction and engagement of large classroom-size audiences. A third experiment and a case study were designed and described here, after explaining our audience interaction approach and the revisions made to our testbed application to support it.
Chapter V – Audience Interaction

5.1 Supporting Audience Interaction

Our third experiment focused on examining the potential effectiveness of audience interaction (for a definition and some examples see Section 2.2.4) for learning in museums and similar spaces of informal education. As we saw in our literature review, simultaneous visitor interaction has been limited to LBEs, where focus is on entertainment—such as theme parks (Schell & Shochet, 2001), and has rarely been used for the active involvement of a large group of learners. From our own experience working with large group interaction in a dome theater (Apostolellis & Daradoumis, 2010; Christopoulos et al., 2009), we have observed the increased engagement of the majority of the participants while immersed in VEs of ancient places, but have never assessed the learning benefits, if any.

This was the driving force in exploring how to effectively engage large student groups with complex educational material. In order to achieve this we had to define the modes of interaction of the audience and eventually revise the system to accommodate those choices. We found no way to equally engage participants, as a means to increase game experience (including engagement) and improve learning gains—a common finding from our previous studies. Such a problem of creating highly interactive and engaging experiences for large audiences have been puzzling significant players in the LBE arena such as Disney34, which eventually made us reconsider ways to engage the whole classroom.

5.1.1 Types of Agency and Involvement in the Game

We decided to maintain two modes of interaction with a different level of agency, but still provide enough sense of control to the less active group (the audience) as a means to support collocated collaboration among all the students in a classroom. Our main concern was how to support the involvement of the audience, a factor believed to affect their learning. We designed tasks that we thought will increase the perceived interactivity for the audience, which has been shown to support involvement in a topic (McMillan, 2000). We also paid extra effort in making sure the demands of the provided tasks were kept, both in terms of content and frequency, within the skill level of middle school students, as a means to maintain their perceived sense of control but also involvement in and enjoyment with the game (Keller & Bless, 2008).

34 Relayed by Mark Mine, director of the Creative Technology Studio at Walt Disney Imagineering, through personal communication during the Interaction Design and Children conference in Barcelona, 2010.
5.1 Supporting Audience Interaction

Figure 5-1. Setup of the third experiment, involving audience interaction for a whole classroom.

The final implementation allows simultaneous participation of up to 24 students, split into two main interaction modalities: the players and the audience (Figure 5-1). In order to facilitate classroom/audience interaction we decided to maintain two students with direct control in the game using Xbox controllers (players), since from our previous experiments we concluded that the third player in most cases assumed a more passive (less dominant) role, which was sometimes detrimental to her, and the group’s, experience. The rest of the group/class members (audience) are holding iPads and are assigned different tasks in the game depending on the experimental condition. In order to test the effectiveness of our audience interaction design, we defined two conditions: a) one where interaction with the devices aims solely to motivate students to attend to the game (low involvement or LI), and b) one where device interactions support sustained engagement of the students with the game (high involvement or HI).

We will first describe the role of each group of students and their level of involvement with the game, essentially defining the experimental condition, justifying our choices based on the operational definition of involvement previously provided. In the next section, we will describe the interactive system revisions and how they served our goals in facilitating the interaction and collaboration of large groups for both conditions.
5.1.1.1 Supporting Motivation through Interaction

Since this study, like all previous ones, was motivated by classes visiting museums, we strived to create an experience that would be engaging for all participating groups. Thus, after initial discussions with teachers, we replaced the passive setup we originally planned for our low involvement condition—where the audience would simply watch the game play of two students—with a more involved condition—where the audience could still interact without directly affecting the outcome of the game. This condition uses a competitive component as a motivating force to increase student self-efficacy (Vorderer et al., 2003) and attention. Audience choices with the tablet do not affect the outcome of the game in any way (i.e., audience members have no agency in the game), but the competitive factor is believed to foster excitement and enjoyment eventually affecting learning (Garzotto, 2007), maintaining their motivation to follow the game.

From the perspective of the audience, students have to attend to the players’ actions and register when a task is completed in the factory as quickly as possible. Competition affects only audience members, as players are unaware of the audience’s interactions in this condition, and takes two forms depending on the point in the game. During the first part of the game (steam production) the audience plays together as a team, competing with other classes, while in the second part (olive oil production) pairs of students are assigned to watch for tasks in the factory (e.g., when the players start the press). A scoreboard at the end of the game displays the performance of the audience both as an average of the whole class’ response times (for the first part) and as an aggregate of the pairs’ response times (for the second part). Examples of the iPad interface and the scoreboard are provided in the next section 5.1.2.

Since we realized that even with the added audience interaction elements this condition would probably comprise the students’ motivation to attend, we tried to make them feel as if they were part of the game (i.e., workers in the virtual factory). Thus, students in this condition were also instructed to help the players at all times using verbal interventions, to compensate for the long periods of inactivity and lack of direct effect in the game. Social interactions afforded by the collocated nature of this experience were deemed valuable from the outset of our work, and consequently we wanted to exploit the collaborative problem-solving opportunities even when they were not mediated by technology.
5.1 Supporting Audience Interaction

5.1.1.2 Supporting Sustained Involvement through Interaction

The high involvement condition attempts to sustain involvement of the audience in the game, as a means to improve their game experience and social presence, and—according to our hypothesis—learning. By increasing the level of agency of the audience and giving them some kind of control over the outcome of the game, either indirectly through a voting mechanism or directly by executing tasks, we believe that involvement will be supported for a longer time. This dual mode of control was thought to increase the sense of control over how the game proceeds (indirect agency and impact) and the sense of control over specific outcomes (direct agency instances); both of these contribute to intrinsic motivation and engagement, according to flow theory (Csikszentmihalyi, 2000). Moreover, as prior research has shown, decreased levels of perceived control over outcomes might even be beneficial with respect to enjoyment during a task, as long as the degree of uncertainty of one’s impact is kept within some limits (Keller & Bless, 2008).

Hence, we developed a set of activities in relatively frequent intervals, where audience members could affect the game by providing their input. More specifically, in this condition the tablet interface allows audience members to provide feedback to the players by means of a) responding multiple choice questions, b) indicating where to go next, or c) direct interaction by controlling parts of the virtual factory. In the first two cases, feedback from the audience appears directly on the projection screen and players can use it as advice to troubleshoot a problem and move forward in the game. Opportunities for interaction appear on the devices based on players’ actions in the game, such as when approaching a machine with an active problem. The types of prompts presented to audience members serve a triple purpose: a) to test their understanding of the process as presented during the informative video, b) to maintain their attention to the game in order to support the players, and c) to instigate discussions about troubleshooting practices between the players and the audience.

Not all questions provide a direct solution to a problem occurring in the factory. In some cases responses were meant to support the understanding of the specific task being dealt with and students should collaboratively identify how the information is pertinent to the problem at hand. As an example, Figure 5-6 top in the next section shows the tablet interface that enabled Jessica, as an audience member, to identify the different pulleys, while players were trying to attach a belt to one of the machines. The responses of the whole audience appear at the top left window of the
main interface (Figure 5-6), which players could use to identify between which pulleys to place the belt. The responses provided are purposefully not validated by the system, in order to allow all students to reflect on their choices after the correct solution was executed by the players. Additionally, not providing immediate feedback on the correctness of a response was thought to increase playability of the game by promoting exploration and experimentation. Similar to the previous condition, audience members were encouraged to verbally participate and collaborate with the players.

5.1.1.3 Audience Involvement per Role & Condition

The level of involvement (see Section 1.2 for our definition) between our two conditions and the students’ role in each condition were intentionally different. First, the two different student roles as defined by the interaction modality of each role—i.e., players using Xbox controllers and audience using iPads—differ significantly both in terms of the frequency of interaction and the degree of agency of each interaction. More specifically, players are provided with direct agency throughout the whole game using their individual viewpoints in the VE. Unless they chose to release control, they continuously interact within the virtual factory, either through navigation or manipulation of the environment. On the other hand, the audience participates in two conditions that have been deliberately designed to offer a different level of involvement. This happens both in terms of the number of interactive episodes in the game (3 for the LI vs 15 for the HI), but also the degree of agency of each episode. None of the three episodes in the LI condition has an impact in the game (low agency), whereas 2 episodes in the HI condition last longer and directly affect an attribute of the game with the remaining 13 having an indirect impact (see Figure 5-2).
5.1.2 C-OLiVE Reloaded

The exact same virtual environment, the virtual olive oil production factory, was used during this second stage of our work. The objective of the game remained the same, but we reduced the number of tasks the group had to complete to finish the game, in order to fit the game within a school hour. Groups had to operate only one of the two sets of machines in the virtual factory, which involved thirty-two different tasks, using eight items/tools, and interacting with twenty different machinery/process parts. Like before, the group is led through the process using alerts that appear at the bottom of the map (yellow messages) or a player’s window if she is near a problem, and have to identify and troubleshoot problems in a timely manner. Everyone is notified about factory updates with information messages appearing at the top of each window (blue messages); players get action feedback directly with messages appearing on their sidebar.

The screen space left by removing the third player’s viewpoint is now occupied by a window acting as the interface between the audience and the players. Depending on the experimental condition (described above), this window might be blank or used to display a scoreboard from the audience’s choices at the end of the game (as shown in Figure 5-5), or the feedback provided by the audience’s devices per task (as shown in Figure 5-6). Two extra modules were developed to accommodate for the incorporation of the iPads in the game: an iPad_Interface module for handling the communication with the devices, and an iPad_Window module for receiving audience input (through the first module) and displaying it on the top-left window. These two modules work in tandem to receive/send messages from/to the client devices and display any relevant information on the projection screen.

Communication between the system and iPads uses websocket technology and javascript. The computer running the game acts as a server and hosts all iPad interface screens as html pages, while the devices are connected as clients over a wireless network through port 8080. The pages were created using the Bootstrap web-developing framework, which was deemed appropriate for implementing a responsive web-based application for the iPad, and most of them are created dynamically with content passed to the devices from the game engine based on player actions. The iPad login page (Figure 5-3 left) was used to create a stand-alone app (Figure 5-3 right), where there is no address bar and scrolling is locked. We also used cookies to store data locally on each
device, just in case the app exits in the middle of the game (although we used Guided Access on the iPads to lock the app during our studies).

![Figure 5-3](image)

**Figure 5-3.** The iPad login screen (left) and different app icons we have used during our research (right).

### 5.1.2.1 Audience Interaction Scenarios

We provide here a more detailed account of the interactions audience members can perform during the game. Players have to follow the exact same gameplay route as described before (see Section 3.3), with the exception of having two players, instead of three, dealing with only one set of machines (due to time constraints, as mentioned previously). Since the two conditions were largely different in terms of the iPad interface and actions supported, we will present them separately providing working examples regarding their functionality.

#### Low Involvement Interface

Initially, audience members have to login using the code name they selected during completing the background survey (details about the experimental design can be found in section 5.2.2). In the first part of the game (i.e., steam production), all audience members have to register when an action happens in the factory by the players. There are four actions in total (loading the boiler, starting the fire, attaching a belt, and starting the engine), which are displayed in the iPad interface shown in **Figure 5-4** (left). After each one of those tasks is performed by the players, every student from the audience has to click the corresponding button as quickly as possible. In the example presented in the images below, *Olivelover* correctly identified when the boiler was loaded (green check mark), but prematurely selected that the fire was started. Audience members have to click all buttons to proceed to the next screen, regardless of their performance.
5.1 Supporting Audience Interaction

Figure 5.4. The iPad interface during the first—steam production (left) and second—olive oil production (right) stage of the game, in the low involvement condition.

After the first stage is over, audience members are automatically assigned in dyads to one of the second stage’s (i.e., olive oil production) tasks. In our previous example, Olivelover was assigned to attend when the mill will be loaded (Figure 5-4 right). As soon as this action was performed in the game, he had to click the corresponding button on the iPad, hoping that his peer will do the same equally fast. The aggregate of their response times appears on the scoreboard presented at the end of the game, along with the average class time per task for the first stage (see Figure 5-5). There are 11 tasks in total assigned in pairs, which equals to 22 students who can participate as an audience in this condition. In order to maintain the students’ attention, a final question about the ratio of olive oil to olives is presented on the iPad interface at the very end of the game, when the last task (i.e., weighing the oil) is completed by the players.

Figure 5-5. The scoreboard for the low involvement condition in a class of 20 students during our experiment.
High Involvement Interface

Similar to the previous condition, audience members have to login to the game by entering their chosen code name. Interaction opportunities occur when one of the players approaches a machine with a problem (a yellow alert icon). If there are multiple problems, a queue is holding the order of the problems that players approached, and presents the corresponding question screen on the iPads in the same order. As an example, player Jim approached the Laval separator No1 in the virtual world (blue avatar in Figure 5-6 bottom) and as a consequence all iPads are presented with a question asking to identify the different pulleys in a diagram (interface shown in Figure 5-6 top). The question appears simultaneously at the top-left of the game interface and the iPads, with the difference that the available choices are not displayed in the game window to avoid priming the players about possible actions before the audience cast their vote (i.e., the gray bubbles are missing altogether from the diagram shown in Figure 5-6 bottom).

The available time for reading and responding to a question is 25 seconds (timer starts after the first 5 secs to allow students to read the question). Audience member choices are logged right away (i.e., sent to the game server), so students are free to change their selections as many times as they wish in the allotted time. The iPad interface in Figure 5-6 top shows the (correct) choices made by audience member Jessica, with seventeen more seconds remaining. After the timer expires, the majority votes are displayed on the diagram of the game interface, which in our example happen to be the same as Jessica’s choices. In multiple choice questions a green color indicates visually the most popular response(s). When the audience is asked to indicate a point on the map (e.g., “Which machine was used to control the pressing process? Where is it?”), their responses are logged as map coordinates and displayed as red spots on the game’s map window (top-right).

There are fifteen (15) opportunities for audience interaction in the high involvement condition, divided in five main task categories:

- **CHOICE**: Select a response out of four available in a multiple-choice question.
- **IMAGE1**: Select the correct response from options displayed on a machine image.
- **IMAGE2**: Identify different machine parts or process steps in an image (example).
- **MAP**: Indicate where something is located in the factory by clicking on the map.
- **ACTION**: Perform a task in the game by manipulating the interface or the iPad itself.
5.1 Supporting Audience Interaction

Figure 5-6. The iPad interface (top) for the first problem used during the practice session, and the game interface (bottom) right after players completed the task, with audience responses displayed at the top-left.

For reasons of completeness, we include a table of all audience tasks, their category/type, and the corresponding question appearing on the iPad (as they are being read by the game engine from an external Excel file called iPad_Tasks.xlsx) in Appendix C. We also include screenshots of the corresponding iPad interfaces (one for each task category), enabling audience interaction as described above, under Appendix C.
5.2 Experiment III

The aim of this third experiment was to investigate how different levels of audience interaction might affect its members’ engagement with the content, and eventually how much (learning) they get out of the experience. In order to achieve this, we conducted a large-scale experiment in public middle school classrooms in our area (Apostolellis & Bowman, 2016). Students using either game controllers or tablet devices (i.e., iPads) simultaneously participated in the game, assuming different levels of involvement at different times, based on their assigned role in the game but also the experimental condition. Once more, we assessed their subjective game experience, social presence, and also learning gains (through pre/post-test scores). Eventually, our goal was to respond to our last research question:

RQ4: How does the level of involvement of a large audience of students affect game experience, social presence, and eventually learning during collocated collaboration?

Finally, based on our previous study on how cultural differences can affect learning by mediating the interactions of students with technology (Apostolellis & Bowman, 2015), we were motivated to look at a more fine-grained level on the impact of the socioeconomic status (SES) on learning. This was enabled by running the study in two highly different small urban areas regarding demographics, with one school being located in a labor class town and the second in a University town. We assumed and eventually confirmed that these factors will affect socioeconomic status (indicated by the number of student meals being subsidized and number of counselors assigned per school), as well as academic achievement (indicated by official school reports). The extra research question we tried to address based on SES was the following.

RQ4.1: How are involvement level and learning affected by the socioeconomic status (SES) of students, during a collaborative game experience for the whole classroom?

5.2.1 Hypotheses

Due to the innovative nature of our study, our hypotheses are based both on empirical findings from previous experiments as well as on existing literature. More specifically, we hypothesize that higher levels of audience involvement (H4a) and agency in the game (H4b) will increase learning, as indicated by (Apostolellis & Bowman, 2014), but only if both groups’ interactions are adequately facilitated by an expert guide, as was revealed in (Apostolellis & Bowman, 2015).
Agency has been connected with learning in the past, especially through children’s individual interactions in an educational VE (Roussou, 2006), but in some cases it can obscure learning by overloading the user’s cognitive capacity (Sweller, 2005). Moreover, in our previous studies participants in the high interactivity/collaboration conditions expressed enhanced GE and SP, which we assume will be the case for a large student group, too.

The interplay of GE and SP with learning has been the main focus in our prior studies, in which we did find them to be associated. Nonetheless, the effect of GE on learning has not been studied adequately, especially for larger groups, but individual elements such as engagement or immersion in the story (Dede, 2009), (social) competition (Vorderer et al., 2003) as a function of enjoyment (Thomas W. Malone & Lepper, 1987), and flow in the form of motivation (Csikszentmihalyi & Hermanson, 1999) have been connected with improved learning gains. SP has been mostly studied in the context of online learning communities (Cui, Lockee, & Meng, 2012) and distributed collaborative VEs (Sallnas, 2005), but we hypothesize that these findings might apply to the collocated nature of the current study, as well. Thus, our overall hypothesis is that the more involved the students and the higher the agency in the game, the more they will experience high GE and SP, leading to improved learning outcomes (H2).

Regarding RQ4.1, we hypothesize that students from a higher socioeconomic class will perform better in the game and achieve greater learning gains (H4.1). This is based on evidence concerning both a more independent learning style for these students (Shade, 1989), but also the different goal orientation favoring learning of high-achieving students (Dweck & Leggett, 1988), more common in this social class. Finally, we recognize that the multimodal character of the interaction (including student interactions in the physical and virtual space) and complexity of the experiment provide ample opportunities for further analysis, involving the juxtaposition of qualitative and quantitative data. To investigate potential findings from such social and technology-supported interactions we attempted an extensive temporal analysis of recorded data, presented in the Analysis section. Nonetheless, due to the lack of previous work on behavior and social signal analysis for large groups—research has been rather focused in meeting settings where turn-taking can be usually easily defined (Pantic et al., 2011)—we have no directed hypotheses about potential findings.


5.2.2 Experimental Design

Based on the aforementioned setup description, we ended up with two levels of involvement (IL), as the between-subjects independent variable: *Low Involvement*, where audience members need to attend to the game and register tasks on their devices (just to keep them motivated); and *High Involvement*, where the audience provides their feedback to players at different points, and must also perform some tasks in two cases. The first setup is typical of existing museum guides for large student groups, with the extra motivating factor; the second is the one we hypothesize will afford an improved game experience and greater learning benefits, if both are properly facilitated, based on the mixed findings from our previous studies (Apostolellis & Bowman, 2015).

The main dependent variable was learning, while GE and SP were secondary ones. Learning was measured as the score difference between a pre-test (taken almost a week before the game to avoid priming) and a post-test (taken one or two days later, based on the class schedule). This was a quiz about the content of the game and was divided into three parts. Similar to our previous experiments, the first part (12 questions) asked about factual information presented in the game; the second part (5 questions) assessed conceptual knowledge of the domain, requiring students to combine information presented in the game; and the last part (10 questions) evaluated their understanding of collaborative tasks performed in the factory. Since we wanted to focus more on the students’ conceptual understanding of the olive oil production process, two of the questions from the previous questionnaire version asking purely factual information were replaced. More specifically, questions Q8 and Q15 were replaced with questions assessing a broader understanding of the mechanics of the process being presented. The questionnaire used in this (and the previous) experiment can be found in Appendix A.

Similar to our previous studies, we used subsets of the Game Experience (GEQ) and Social Presence (SPGQ) questionnaires, developed by the Game Experience Research Lab at the University of Eindhoven (de Kort & Ijsselsteijn, 2007; Ijsselsteijn et al., 2007), to measure these two constructs. We found them appropriate self-report instruments for collaborative games, as they are more sensitive to a broader range of emotions associated with digital game experiences and also include versions designed specifically for kids. The GEQ is broken down into seven different dimensions that contribute, positively or negatively, to the game experience: *immersion* in the story, *flow, challenge, competence, positive and negative feelings*, and *tension* (Ijsselsteijn et al.,
The three constructs of the SPGQ are appropriate for the collocated nature of the game: psychological involvement encompasses positive (*empathy*) and negative emotions towards co-players, while *behavioral involvement* captures the degree of player interdependence, which is significant in social game experiences (de Kort & Ijsselsteijn, 2007).

### 5.2.2.1 Participants

Our goal was to have a very large sample for two main reasons: to increase the sensitivity of our analysis (i.e., be able to capture even subtle differences between conditions), and to have a large enough sample of players to enable a valid comparison with the audience members. We eventually had 572 students start the study, 507 play the game (included in our analysis), and 476 complete all three steps (pre-test, game, and post-test). They were all middle school students between 10 and 15 years old (M = 11.8), mostly 6th (46.75%) and 7th (38.25%) graders, with slightly more males than females (267 boys, 240 girls). Being an inclusive experience, we allowed students with any kind of intellectual disability to participate. We had seventeen groups participate in each condition, with a very balanced distribution (Low: 254, High: 253).

We also tried to balance the time the post-test was taken across conditions, with 226 students taking the test one day later (Low: 108, High: 118; 8 classes each) and 250 students two days later (Low: 126, High: 124; 9 classes each). This was constrained by an A/B class schedule (i.e., classes meet every other day) for more than half of our sample. The study was conducted during a period of two months, with the collaboration of six teachers (two Technology Education, two Business, one AgriScience, and one Family and Consumer Sciences), in two Montgomery County Public Schools (MCPS) in Virginia, US. The research study was approved by both the Virginia Tech Institutional Review Board (IRB) and the school district (see Appendix A).

### 5.2.2.2 Apparatus

The game was projected on a large front-projected 16:9 screen inside the school auditorium (either the main hall or the stage), and students sat at a distance of around 4 meters, with players sitting slightly closer (see Figure 5-7). We used a Dell XPS laptop with Intel Core i7 processor and an nVidia GeForce GT 750M graphics card. Wireless Xbox controllers were used as interaction devices for the players and Apple iPad 2 Air devices for the audience. The pre and post-study questionnaires were administered in the classroom using the same iPads to enable automatic recording of responses.
Figure 5-7. Setup of the third experiment for both conditions, in public middle schools.

5.2.2.3 Procedure

We initially met with the teachers and recruited them using a demonstration of the system and study explanation material. At the beginning of the school year we started to book the school visit dates, based on the schedule of each teachers, and administered the parental permission forms. The study included three days at school. During the first day, approximately one week ahead of the game day, the class was introduced to the study by the researchers. Then, after getting their verbal assent, they completed the background survey and the pre-test, using the provided iPads. Students selected a code name, which was used to identify their responses on all forms and match them with the game data. During that day we also selected the students acting as the players, based on their gaming experience level and feedback from the teacher. An attempt for mixed-gender players was made, but priority was given to players with 3D game experience, playing more than 3-5 hours per week.

The second day involved the actual game, and all classes met in the experiment venue. Classrooms were assigned to one of the two experimental conditions, usually alternating the order
but making sure there was an almost equal distribution of students between conditions, especially in A/B schedule classes. Students were initially introduced to the procedure and then watched a five-minute video about the production of olive oil and the machinery involved. After announcing the two players, we explained the roles based on the experimental condition and handed the devices to all students. A brief practice session, part of the main trial to reduce the duration of the game and fit it within a school hour, enabled students to get accustomed to the interaction devices, the game interface, and the style of collaboration between them. This session included solving the first problem (collaboratively attaching a belt between two pulleys using a wrench).

After the practice was over, students were left to play by themselves. Guiding tips were provided if they were stuck at the same problem for more than one minute, to make sure they finished within the time limit. During game play, which was video recorded for further analysis, we noted the most vocal players by code name. A variety of time-stamped game data were logged: actions attempted (errors) and tasks performed, stations visited in the factory, full location log (every second), machine state changes, total score, and game duration. Right after the game, all students completed the game experience and social presence questionnaire; an informal discussion with students followed when time permitted.

On the third day students were asked to complete the post-test. This delayed assessment was imposed by the limited time during a school hour, but also ensured that information recall was based on long-term memory. The difference between pre/post-test scores was used as a measure of learning gains, attributed to the game intervention. A brief semi-structured interview with the teacher was conducted during that time, requesting their feedback on the overall experience. Finally, the teacher was thanked for her contribution with a $25 gift card and classes were thanked and awarded a certificate of game completion, documenting their performance in the game.

### 5.2.3 Results

All but four groups (56 students) finished the game, all in the High condition (the game had to be stopped five minutes before the class ended). Since their post-test scores and logged game data did not divert considerably from the mean we decided to include them in the analysis. After matching all data based on code name, we ran exploratory statistics to look for outliers and missing values. Extreme values (more than three standard deviations away from the mean) in the quiz scores were substituted using Winsorizing (Field, 2013). In the pre-test this practice corrected high scores from
students who clearly used guesswork (some even scored lower in the post-test), while in the post-test it addressed students who responded “I don’t know” to all questions. Throughout our main analysis presented below, we made sure that the statistical models used satisfied the necessary assumptions and corrected values are reported whenever these assumptions were violated. We recognize the increased potential for error when running multiple tests. Since practices vary across the research community for handling this, we opt to present the original significance values, but we consider the potential error when interpreting the results.

5.2.3.1 Effects of Involvement Level and Agency on Learning

Effect of Involvement Level on Learning [RQ1]

In testing our hypothesis for RQ1, we ran a one-way mixed ANOVA with the time the test was taken (before and after the game) as the within-subjects variable, and involvement level (High or Low) the between-subjects variable. We found a highly significant effect of the time the quiz was taken on the score, \( F(1,474) = 2211.05, p < 0.001, r = 0.91 \), indicating that overall, students performed significantly better on the post-test compared to the pre-test (Figure 5-8; all bars show std. error). There was no significant interaction effect of the condition (involvement level) and the time the quiz was taken, \( F(1,474) = 3.176, p = 0.75 \), indicating that learning between the low and high involvement groups were similar \( (M_{\text{low}} = 34.42, M_{\text{high}} = 37.13) \).

![Figure 5-8. Effects of involvement level on learning.](image)
Effect of Agency in the Game on Learning [RQ2]

We ran a two-way ANOVA with the interaction modality (defining the degree of agency in the game) as the second between-subjects independent variable and score difference as the dependent variable (since we already knew there was a significant difference between pre and post-test scores). We found that there was a highly significant main effect of interaction modality on learning, with the players revealing greater gains compared to the audience members (M_iPad = 34.68, M_Xbox = 42.7), F(1,472) = 13.385, p < 0.001, r = 0.17, indicating the importance of direct agency in the game for educational purposes (see Figure 5-9). There was, however, no interaction between involvement level and interaction modality, F(1,472) = 0.536, p = 0.512, r = 0.03.

![Figure 5-9. Effects of agency and involvement level on learning.](image)

Effect of Involvement Level on Information Retention

In deepening our understanding on the impact of involvement on learning, we wanted to check if the varying interval of students’ assessment could affect information retention. Thus, we split the data in two categories depending on the time between the game and the post-test: one day for the regular schedule (N = 226) and two days for the A/B schedule (N = 250). We ran the mixed one-way ANOVA again and found, as expected, that the highly significant learning gain between pre and post-test remained for both categories. There was no significant difference in learning between
conditions when the test was taken the next day, $F(1,224) = 0.177$, $p = 0.674$, $r = 0.03$. However, when it was taken after two days there was a significant improvement in learning in the High condition, $F(1,248) = 4.135$, $p = 0.039$, $r = 0.13$. Although this was a small effect, it is indicative of the potentially positive effect of engagement on the learner’s capacity to retain information for a longer period of time.

**Correlation of Player and Audience Learning**

We also thought it would be interesting to investigate if there was any connection between the players’ and the audience’s learning. Thus, we split the score differences of all groups in two categories, depending on the control type, calculating the mean of their learning gain per category. We then graphed this mean per condition across all groups and found that there was no correlation of the learning gains between players and audience members in the High condition, with six instances where the players scored lower than the audience members. However, the learning gains of players seemed to correlate with audience members in most of the Low condition groups, especially between groups L9 and L13 (see Figure 5-10; group L4 missed the post-test). There were only three instances where players revealed a lower understanding compared to audience members, two of them before the pattern emerged. It is interesting to note that the pattern coincides with the classes of the second school, where students had a different academic and socioeconomic profile (more under Discussion).

![Figure 5-10](image-url). Correlation of learning gains of players and audience across all groups of the Low condition.
5.2.3.2 Effects of Involvement Level and Agency on GE and SP

Effects of Involvement Level and Agency on Game Experience

We ran t-tests for each one of the GE measures and game experience as an aggregate of all the measures, inverting the value of the negative ones (i.e., tension and neg. affect). In all cases we used bootstrapping to reduce the effect of any potential bias in the model. We found that among all the measures, there was a significant difference only in immersion in the story, with High condition students feeling more immersed; corrected t-statistic due to heterogeneity of variances $t(502) = 2.010, p = 0.045$. We then ran the same tests after segmenting the data based on control type (players vs audience) and found that for audience members the only difference was challenge, which was significantly higher in the High condition, $t(437) = -2.424, p = 0.016$, as expected based on the constant demand to interact with the iPads. For players there were quite a few differences between the two conditions, with Low condition players reporting significantly higher feelings in three of the measures: immersion in the story, $t(66) = 2.611, p = 0.011$; positive affect, $t(66) = 2.279, p = 0.026$; and challenge, $t(2.862) = 0.006$. GE as a whole was also found to be significantly higher for the Low condition players, $t(66) = 2.147, p = 0.035$. Finishing the game or not did not affect GE for neither of the two groups. Overall, these results did not confirm our hypothesis regarding increased GE due to higher involvement.

Comparing all the GE measures across the two control (agency) types, we found a highly significant difference between all the measures ($p \leq 0.001$) with players revealing more positive and less negative feelings compared to the audience, besides tension where there was no difference (see Figure 5-11). T-test statistics: immersion, corrected $t(102.37) = -5.052$; competence, $t(505) = -5.167$; flow, corrected $t(100.15) = -5.215$; positive affect, corrected $t(95.62) = -6.923$; challenge, $t(505) = -5.890$; negative affect, corrected $t(109.61) = 6.739$; and overall GE, corrected $t(96.76) = -7.573$ (corrected statistics reported where equal variances were not assumed based on Lavene's test). These results confirm our hypothesis about the positive effect of agency on GE.
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Figure 5-11. Effect of agency in the game on game experience.

**Effects of Involvement Level and Agency on Social Presence**

We ran T-tests for each one of the SP measures and social presence as an aggregate of all the measures, inverting the value of the negative feelings. Only behavioral involvement was found to be significantly higher in the Low condition, \( t(505) = 2.010, p = 0.045 \). Once more we ran the same tests after segmenting the data based on control type and found that for audience members the only difference between the self-reported SP measures was behavioral involvement, which was significantly higher in the Low condition, \( t(437) = 2.531, p = 0.012 \). There were no significant differences in social presence measures between conditions for the players, which reveals the predominantly individualistic style of game play that most of them assumed. None of the SP measures were affected by the fact of finishing the game or not for audience members; however, players who did not finish the game revealed significantly more negative feelings (i.e., shame, shyness, and jealousy) compared to the ones who did finish the game, \( t(66) = 2.704, p = 0.009 \).

Comparing all the SP measures across the two control types revealed a highly significant difference between all the measures \( p \leq 0.001 \). More specifically, players revealed higher feelings of empathy, \( t(505) = -3.242 \), behavioral involvement, \( t(505) = -7.890 \), and overall social presence, \( t(505) = -6.797 \), compared to the audience members (see Figure 5-12). This was not the case for
negative feelings, where the corrected $p$ value was marginal at 0.049, but was not verified after bootstrapping ($p = 0.062$). Overall, social presence seems to be positively affected by agency.

![Figure 5-12. Effect of agency in the game on social presence.](image)

### 5.2.3.3 Effects of Socioeconomic Status on Learning \[RQ3\]

Our analysis also involved the impact of the socioeconomic status of the students on the main outcome, learning. Socioeconomic status (SES) was defined by the Department of Education official accreditation results (using the ‘economically disadvantaged’ indicator), the location of the school, and testimonies by teachers. SES has obvious implications on the students’ achievement as well, which is also verified by success rates in state-wide tests reported for each school. More specifically, the latest 3-year average result for all students tested in English, Mathematics, History, and Science at the low SE area school was 75.25%, while for the high SE area school it was 85.25%.

In order to investigate this, we ran a two-way ANOVA with involvement level and school as the two independent variables. Our analysis revealed a main effect of school on learning gain, $F(1,472) = 9.049$, $p = 0.003$, $r = 0.14$, with students from the school in the higher SE location ($N = 165$) showing higher learning gains ($M_{diff} = 5.21$) than the students from the school in the lower
SE location (N = 311). There was no interaction effect between the two variables (see Figure 5-13). The interaction graph indicated a larger improvement in learning for the High condition in the lower SE school (M_{dif} = 3.187), as compared to a virtually equal gain in the higher SE school (M_{dif} = 0.09), which however was marginally non-significant as shown by a t-test after splitting the sample by school, t(309) = -1.712, p = 0.088. We can infer then that our hypothesis was confirmed, with students’ SES predicting learning in a great extent, regardless of their involvement level in the game.

![Figure 5-13](image-url)  
**Figure 5-13.** Effects of SES and involvement level on learning.

### 5.2.3.4 Within-group Social Interactions

We were also interested to identify how the social behavior of the group affected game play strategies and performance, and eventually the potential impact on learning gains. Hence, we constructed some high-level questions such as “How does vocal involvement of players and/or the audience affect problem solving in a large group collaborative setting?” and more detailed ones like “How is the distribution of labor managed and is it affected by the audience, in such a setting with two players?” Our strategy involved two main routes: a) use basic analysis of audio recordings and observation data, and b) run a more thorough analysis of all temporal data (including logged game data) and transcripts of the video recordings, if possible.
As mentioned earlier, students were generally encouraged to collaborate closely and work together as a team. However, we noticed that the degree to which this was implemented by the group varied greatly between classes, with some groups being more vocal than others. Using audio analysis of the video recordings we identified the most and least vocal groups, based on the percentage of talking during the trial. “Talking” time was defined as any sound which was higher in energy (i.e., amplitude) than a threshold value. We used Matlab to parse all audio files and check the result with the original video, adjusting the threshold value to account for differences in recording quality. We found that classes participating in the Low condition were vocal on average 60% of the game duration (12.7 mins), while High groups only 46% (10.4 mins), out of a mean trial duration (excluding practice time) of 21.1 mins for the Low and 22.5 mins for the High condition, respectively. We believe that the Low groups were more verbally involved to compensate for the lack of interaction opportunities, which partly facilitated their learning.

Additionally, in this basic type of analysis, we were interested to see how the level of social participation of individual students affected their learning. Although it was hard to keep detailed notes while facilitating the gameplay (i.e., intervening during extended troubleshooting), we did keep an account of the most vocal audience members (identified by their code name). Averaging their score differences (N = 30, M = 53.00) and comparing them with the rest of the audience sample regardless of condition (N = 381, M = 32.11), revealed that these students had a much higher learning gain. We present this as a tentative finding and we have deliberately not used any statistical analysis, mainly due to the occasional nature of this observation (i.e., we could not identify individual students’ code names a posteriori from the videos).

In our more detailed analysis, we parsed all game data (i.e., user interactions, machine states, player location, problem lifespan) in a manner that could be placed on a timeline and analyzed in light of students’ dialogues. The goal was to identify patterns of audience behavior that could potentially explain player actions, as well as GE/SP and learning outcomes. We used the interactive data-driven discovery process suggested by Miller and Quek (2012), in trying to identify an audience interaction behavior model explaining these outcomes. Data for each group were initially transformed into a list of temporal events (data stream) in the following format (where e is each individual event) and were displayed on a timeline (see Figure 5-14):

\[
e_{\text{start\_time}}, e_{\text{end\_time}}, e_{\text{description}}, e_{\text{actor}}, e_{\text{recipient}}, e_{\text{type}}
\]
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**Figure 5-14.** Example of the exploratory analysis we followed using temporal game data.

The image of **Figure 5-14** is a 60-sec sequence from one of the groups, with eight separate event tracks: action for each player, two tracks for the lifespan of problems, proximity of each player near workstations/machines, and player movement data. More tracks were available but not displayed all the time, such as inventory items and machine states. The way we used the analysis tool was to watch each session’s recording along with the sequence of events (the tool allowed synchronous playback) and identify points of interest, in terms of social interactions and events happening in the game. In the example above, we noticed that players proceeded very cautiously in trying to find the right action for the problem at hand (indicated by sparse clicks when the problem first appeared), and kept inactive right after iPad responses appeared on screen. As soon as the audience became very involved by shouting the correct response and urging players to execute it (as seen in the video recording), the players started clicking frantically until they managed to synchronize their actions and perform the task (i.e., load the empty mill with olives).

Such a sequence of events was considered potentially decisive for the outcome of the game and learning gains, since this was in one of the groups acquiring the highest score overall. This sequence was then encoded as a temporal event description and was used to find similar patterns across all groups by scanning through their data streams (Miller, 2013). This specific example, like most of the interaction sequences we identified through our exploratory analyses, did not reveal any patterns connected with either learning or GE/SP. In other words, social behaviors like this could not be used to predict increased engagement or learning. We should, however, mention that our analysis was not conclusive, mainly because we could not successfully encode audio interactions on the temporal scale. We strived to distinguish audio data in three main categories (player talk, audience talk, and facilitator intervention), in order to acquire a fine level of understanding of how different utterances might have influenced the game progress. We tried various approaches, such as using a specialized speech processing tool for discourse audio analysis.
called COVAREP (Degottex, Kane, Drugman, Raitio, & Scherer, 2014), with varying levels of success mainly caused by the unequal audio quality due to space and microphone variations. We also tried automatic\textsuperscript{35} (using advanced speech recognition algorithms) and manual\textsuperscript{36} transcription of video recordings, with complete or partial failure due to the extremely complex social environment and inadequate video/audio quality, which made it impossible to recognize individual student voices (e.g., distinguishing players from audience, especially during high energy instances).

5.2.3.5 Effects of Game Performance on Learning

We did experiment with other forms of exploratory analyses, trying to identify how game performance might have affected the outcome, regardless of social interactions. We focused mainly on high and low-achieving groups (i.e., groups with the highest or lowest learning gains), as our goal was to identify how game play might have affected the outcome in a negative or positive way. High/low achievement was defined as deviating by the mean more/less than the mean of all standard deviations. In this case, we used various visualization techniques to explore game interaction data from a high level view (compared to the more focused view described before) in hopes of gaining an insight of how player performance might have affected the outcome. For even greater depth, we considered group learning gains in terms of both players and audience.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5-15.png}
\caption{Troubleshooting duration per game task for the high-achieving player and audience groups.}
\end{figure}

\textsuperscript{35} We tried both offline tools but also cloud-based Speech-to-Text services, such as IBM’s Watson (https://www.ibm.com/watson/developercloud/speech-to-text.html) and Google’s voice recognition API (https://cloud.google.com/speech/)

\textsuperscript{36} We used the video annotation tool VCode on a Mac computer (http://social.cs.uiuc.edu/projects/vcode.html)
**Figure 5-15** shows an example of such a visualization, where we plotted the duration of all tasks where the audience could participate in the High involvement (HI) condition, or that they had to attend to in the Low involvement (LI) condition. We included groups in which both players (groups H10, H12, H15, L8, L10, L14, L16) and audience (groups H3, H8, H11, L7, L10, L11, L13) performed higher than the mean ($M_{HI\text{-players}} = 40.66; M_{HI\text{-audience}} = 34.97; M_{LI\text{-players}} = 42.30; M_{LI\text{-audience}} = 39.93$). We did not notice any common patterns of some task(s) being more or less challenging (taking a longer time to complete) than others across these groups, besides the first task (i.e., 23: *belt_attach*), which we used as a practice task and took expectedly longer. The variation in troubleshooting duration across all other tasks, even when compared to the corresponding performance of the low-achieving groups, did not indicate a potential correlation of game strategy or performance with learning.

We also looked at the performance of players per group, focusing once more on low and high-achieving groups. We were mainly interested for groups that revealed a large difference between player and audience performance; we wanted to understand what might have caused such a difference in terms of both game play and social interactions. The plot in **Figure 5-16** shows all the interactions of the players (controller button presses) who revealed the second highest learning score improvement between pre/post-test ($M_{H15\text{-players}} = 47.25$). It is apparent from the graph that P2 performed the most tasks (more green dots on vertical lines) but was slightly less cautious about when to click the controller button in order to execute a task (more trailing dots before a green dot). Observation of the interactions of these two students made it clear that P2 was experimenting and clicking much more often than P1 (multiple green dots indicate an attempt to synchronize the press of the button with the other player, while performing a correct action).
What is even more interesting though, is that the audience of this group revealed the lowest learning improvement compared to all 34 groups ($MH_{15\text{-audience}} = 24.89$). This group was also amongst the most silent of all the groups; even the players failed to communicate with each other efficiently after our repeated attempts. Consequently, although their game performance appeared to be effective and their understanding about the process significantly improved, their highly individualistic and inconspicuous gameplay deprived the whole group of the opportunities for social interaction that could afford greater learning gains for the whole group. This was not the only group exhibiting such a behavior, but it was probably the most prominent in terms of the detrimental implications of uncooperative players on engagement and learning for the whole class.

### 5.2.4 Discussion

This was admittedly a large and complex study in which we tried to understand the role of involvement and agency during a large-group, collaborative, learning game. Our hypotheses concerning the effect of audience involvement on learning (H4a), but also on game experience, and social presence (H2) were not supported, and we can attribute this to various factors. First, we realized that the frequency of interactions in our High involvement condition was accepted with mixed feelings by students, depending on their gaming experience and general attitude towards digital games. Such feelings fluctuated between “extremely challenging” and “too boring,” to use some of the comments received. Second, the choice of players had a considerable observed impact on the whole group’s experience, with some players focusing too strong on finishing the game while ignoring the feedback offered by the audience, or even their co-player. Last, the design of the audience interaction did not explicitly support social dialogue, with many students relying solely on their devices as a means of influencing the game.

A significant finding of this study is the increased learning for game players compared to audience members (H4b). This can be clearly attributed to the increased agency in the game that these students had, which facilitated the retention of information. This also overlaps with other studies, which explicitly investigated the impact of interactivity on learning (Roussou, 2006), although in our case the comparison was more focused on collaborative game play facilitated by collocated social interactions. Combining the effect of agency on learning with the overall more positive game experience and increased social presence for the players as compared to the audience, supports the interconnection of highly interactive (gaming) educational experiences with improved
learning gains. This is not to say that all students should have an equal level of control, but rather that we should design for memorable and meaningful learning activities, as a means to more effectively facilitate the construction of mental models, taking advantage of the capabilities of the medium being used (Kozma, 1994).

Although our main hypothesis regarding RQ1 was not verified for the whole of our sample, we consider the impact of involvement level on retention of information to be an important finding. This is indicative of the long lasting impact that (highly) involved game experiences can have on large audiences, which is the main goal of museums and other similar spaces of informal learning (John H. Falk & Dierking, 2000). Part of the result may be attributed to the higher level of challenge experienced by audience members in this condition, a contributor to learning if aligned with skills (Csikszentmihalyi & Hermanson, 1999), caused mainly by the increased demands to participate through the iPads. On the other hand, it seems contradictory that the Low condition audience expressed greater behavioral involvement. However, this can be attributed to the teamwork spirit experienced in many cases by audience members in the Low condition, making them feel they were more connected with peers, as compared to the High condition, where iPad interventions might have negatively affected social interactions. Nonetheless, we recognize that it is possible that this result is a false positive due to experiment-wise error. A longitudinal study is needed to provide deeper insights.

Comparing GE measures for the players between the two conditions, it was interesting to find that the Low condition afforded a better game experience. This might be attributed to the more vocal interventions of the audience observed in this condition, substituted by the digital mediation through the iPads in the High condition, which enabled players to enjoy the game more (expressed through increased positive affect and immersion), but also felt more challenged as they had to attend to the audience’s continuous feedback. This is further supported by the association of their learning with the learning of the participating audience in most of these groups (shown in Figure 5-10). On the other hand, the disassociation of learning between the players and the audience in the High condition is indicative of how the mediation of interactions through technology can socially isolate the players in such settings, negatively impacting learning (many of them scored lower than the mean audience score). This was also revealed by the highly individualistic game play many of the players in this condition manifested (such as the example of group H15 mentioned above), often ignoring—and eventually discouraging—hints provided from the audience.
Furthermore, the study revealed that the socioeconomic status and academic performance of the students does play a role in the capacity to learn through a complex 3D simulation game (H4.1). It is interesting to mention that all twelve classes from the higher SE school were on an A/B schedule, meaning they completed the post-test two days after the game. This has two implications on our findings. First, it means that the students of the higher SES learned significantly more although they had the extra burden to retain the information for two days. On the other hand, the fact that retention was improved for the High condition may partly be attributed to these students, who comprised 41% of the High condition sample. Nonetheless, a more involved interactive experience seems to be more beneficial for students coming from a lower SES, perhaps because a passive experience makes it more challenging to maintain their involvement and interest. It is also interesting to note that the largest correlation between player and audience learning gains was noticed for the Low condition in the higher SE school (groups L9-L13 in Figure 5-10), which possibly indicates the audience’s greater capacity to stay focused even when fewer interaction opportunities are provided.

Last, we should not underestimate the effectiveness of the game as a learning tool for a group of middle school students, which is a major motivation of our work. Both conditions proved to bear considerable promise for engaging a whole class, as also attested by all the teachers during the interview. Design implications of our work indicate the need to increase interaction opportunities for the audience, as a means to maintain their attention to the game and connection with the players, both of which were shown to affect learning. All sensory, intellectual, and emotional opportunities for involvement should be carefully nurtured in this rich social setting, as a means to increase the intrinsic motivation of students to participate (Csikszentmihalyi & Hermanson, 1999). Comments such as “the game was cool, but not gruesome enough!” cannot be probably avoided. However, we should design group learning experiences with a focus not only on technological innovation, which undoubtedly speaks to the “digital immigrants” language (Prensky, 2001b), but also on ways to emotionally and socially involve students with each other. It is through this interconnectedness, as has been indicated from our study, that most opportunities for engagement and learning can emanate from.
5.3 Case Study

In order to assess the ecological validity of the proposed instructional approach for large groups, we planned to conduct an informal case study inside an actual museum. The museum would be responsible for recruiting the school groups for their own purposes, giving us permission to use some of their time and space for running the case study. Ideally, we hoped that the subject of the exhibition would be pertinent to some part of the olive oil production process presented with our system; possible examples include food production, complex engineering processes, or Greek heritage. In any case, we aimed at acquiring qualitative data in validating our quantitative results from previous experiments, but also testing our audience interaction design in a real-world setting. Design-based research efforts, such as case/field studies, have been praised for their effectiveness in improving educational interventions by contextualizing design research in a socially constructed process (Bannan-Ritland, 2003). Hence, the three main goals of the case study were to:

- **Test our audience interaction design in a real-world situation:** gaining ecologically valid data was set as one of our main objectives since the beginning.
- **Identify the impact of our intervention in an informal learning context:** making the game part of a mini exhibition or educational activity, where students can improve and express their understanding about the topic in various ways.
- **Refine the design guidelines:** the observations gathered from the previous studies will be tested and refined in an ecological setting.

The case study was conducted at the Franklin Institute in Philadelphia, one of the most renowned science museums in the US. We incorporated C-OLiVE in a mini-course presented to junior students (11th grade) of the Science Leadership Academy high school, the magnet school of the museum. According to the goals mentioned above, the mini-course consisted of two parts, the interactive game and some hands-on activities, designed in order to enable students to express/test their comprehension of the process presented during the game. The setup of the game was identical to the one we implemented during the third study (see Figure 5-7), with two students controlling the game and the audience assisting with the iPads. In the following paragraphs, we present the structure of the mini-course, including the changes we have made to the system and the development of the after-game activity, before describing the case study details and most significant observations.
5.3.1 Mini-Course

The mini-course was offered as part of the weekly educational program of the Science Leadership Academy Wednesdays @ The Franklin, during which 11th grade students visited the museum and attended some kind of workshop. We were given quite some flexibility about the theme of our presentation and we eventually decided to incorporate more information about the engineering and mechanical concepts behind the olive oil production process. Such a decision demanded both revising the system, but also developing an after-game activity in which students could express their understanding and look closer at some of the concepts presented during the game.

5.3.1.1 C-OLiVE Revision

The aim of the system revision was both to address findings from our previous study and to accommodate the demands of being hosted in a science museum. The rationale for the former updates was to improve students’ understanding (learning) of the information presented, increase the engagement of the audience, and improve interaction. The latter updates were implemented in order to better align the game with the theme of the museum and the mini-course. Having these two goals in mind we implemented the updates presented in the following table.

<table>
<thead>
<tr>
<th>Update</th>
<th>Description</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-context info</td>
<td>The 5-min introduction video was broken down in smaller chunks and presented within-context of problem solving; a brief intro video is still presented at the beginning.</td>
<td>Learning (aid info recall)</td>
</tr>
<tr>
<td>Players with iPads</td>
<td>iPads were provided to Players along with the audience to allow them to participate during the questions and maintain their involvement throughout the game.</td>
<td>Learning Engagement</td>
</tr>
<tr>
<td>Correct response</td>
<td>The correct response was displayed on screen right after the players completed a task, to allow all students to understand the correctness of their response.</td>
<td>Learning (impact of choice)</td>
</tr>
<tr>
<td>Freezing action</td>
<td>Interaction on the Xbox controllers and timers in the game froze, in order to allow all students to focus on the video and the iPad interaction when a question was displayed.</td>
<td>Learning (focus attention)</td>
</tr>
</tbody>
</table>
An action task was added where students have to turn a valve by titling their iPads very fast forward/backward; this was added to increase audience engagement.

Animations explaining the movements students had to do during the action tasks were added to the iPad interface; these mini gif animations were created using rotoscoping.

An overlay with instructions about the controls on the Xbox controllers was added on the players’ viewpoint side panel.

The iPad interface allowed users to switch on the fly, accommodating the demands of a dynamic audience setting.

The iPad interface enabled students to select gender, accommodating the lack of a background survey.

The video clips were enriched with information about the mechanics of the machines and the engineering concepts involved (e.g., centrifuge power and steam engine operation).

Table 5-1. C-OLiVE updates and their scope for the system used during the case study at the Franklin Institute.

Figure 5-17 shows the final version of the game interface, while a video clip about the steam boiler operation is being displayed. Both player windows are frozen, indicated by the overlay of a movie strip symbol, while the controls explanation can be seen on the sidebar of the Player 2 window. Figure 5-18 displays still screenshots of the animated diagrams we created to illustrate the engineering concepts included in this version of the game: a) operation of the steam engine, b) hydraulic pumping, c) centrifugal separation of liquids, and d) motion transfer.

The game was tested repeatedly during development, either through informal pilots or by participating in exhibition events. One such event was the Virginia Tech Science Festival, which was organized during fall 2016. As part of the event’s School Preview Day on September 30th, C-OLiVE was hosted at the Science Museum of West Virginia in Roanoke (Figure 5-19 left), while the main event visited by 4,000 people was hosted by the Institute for Creativity, Arts, and Technology at Virginia Tech on October 8th (Figure 5-19 right). Finally, the game and after-game activity (presented below), were tested by undergraduate students attending the Human-Computer Interaction course at the university during the fall 2016 semester.
5.3 Case Study

Figure 5-17. The revised game interface used during the case study.

Figure 5-18. Still images of the video clips we created to explain the engineering concepts used in the game.
5.3.1.2 After-game Activity Development

The goal of the after-game activity was twofold: a) allow students to solidify their understanding about the process presented during the game, and b) act as an informal assessment tool for us to evaluate the effectiveness of the game in teaching about this process. Thus, we devised a 9-foot long printed board on which students could collaboratively reproduce the olive oil production process. To accomplish this the class—split in groups, one for every stage of the process—used 3d-printed models of the actual machinery they saw in the videos and the game, and real-world artifacts such as olives, oil, a belt, pulleys, pipes, etc. The task involved reading the descriptions on the board and placing the items in the provided placeholders, essentially reproducing the mechanical process that was introduced in the game. Figure 5.20 shows part of the board with the descriptions and the placeholders for the first stages of the process.

Figure 5.20. Part of the after-game activity process board (full board included in Appendix B).
The dotted squares are used for placing the 3d-printed machine models. These models were specially prepared using the high-resolution 3d machine models we received from the museum in Greece (where the actual machinery are hosted). We first edited these models using *Maya* and *3D Studio Max* in order to simplify parts that were impossible to physically print and rescale to facilitate assembly. We then inspected them using *Autodesk Netfabb*, a software that checks for open meshes and disconnected vertices and also attempts to remedy any issues and prepare them for 3D printing. The outcome of this process was then loaded on either a *MakerBot Replicator 2* or a *Stratasys Object30 Pro*, depending on the desired level of detail. For larger pieces—such as machine bodies, gears, and pulleys—we used the MakerBot, delivering 0.1mm accuracy by printing in 100-micron layer resolution using PLA filament. The Object30 was used for small pieces and machine parts demanding higher accuracy—such pistons, nuts, and valves—delivering 0.1mm accuracy by printing in 28-micron layer resolution using photopolymer materials. The main difference in technology is that the MakerBot melts a plastic material extruded through a moving head, while the Object30 uses liquid materials that are sprayed on its bed surface through two moving heads, similar to the operation of an inkjet printer.

![The MakerBot Replicator 2 and the Stratasys Object30 Pro used for printing the machine models.](image)

The next step included cleaning and smoothing the printed parts. Cleaning involved removing the support material from every part, which was a different process for each printer. MakerBot support was solid and had to be broken off the surface of the printed item, demanding that the part is sanded afterwards. Object30 support was a soft gel that had to be scraped off and
then totally removed using high water pressure and soaking in a 2% lye solution. Each machine was then assembled by gluing the parts together, making sure that moveable parts could move freely. We initially strived for most machines being moveable, but the cost of achieving this was deemed higher than the benefit students would acquire. Additionally, it would have made the models more fragile during manipulation; thus, we eventually opted to encase them for protection. Finally, we painted the finished model with acrylic water paint and an air brush, after priming them with an enamel primer. In Figure 5-22 we can see the printed parts of the pump, the most intricate machine of all, and the finished painted model.

![Figure 5-22. The 3d-printed water pump before (left) and after being assembled and painted (right).](image)

After this activity was finished and depending on available time, students were exposed to the mechanical concepts presented in the game through the videos. This was done with either small scale models or real-world artifacts operating on some engineering principle presented in the game. Small scale models included a) a mini steam engine, complete with a boiler, a system of belts and pulleys, as well as a belt-driven power drill (see top-left of Figure 5-23); and b) a mini centrifuge machine for separating liquids (see top-right of Figure 5-23). Artifacts included a) an oil pump for transferring liquids (see bottom-left of Figure 5-23); b) two syringes connected with a transparent hose, illustrating the water pump and press operation (see bottom-right of Figure 5-23); and c) a salad spinner using centrifugal force to separate solids for liquids. The goal at this last stage of the mini-course was for students to identify the principles that machines operated on, as presented in the game, and be able to realize how they are being used in the real world.
5.3.2 Study Description

As we explained at the outset, the case study aimed at exposing us to a real-world setting and testing our system with student groups visiting a museum. As a result, no experimental conditions and no formal assessment methods were used. We contemplated on administering a questionnaire either through the school or at the beginning of the experience, in order to gather information about their interests regarding the topic and expectations about the mini-course. We eventually opted to omit such a step, in order to refrain from experimental interventions and maintain the ecological validity of the study. We only gathered general demographic data about the groups (such as their
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gender logged on the iPads) and also recorded their interactions with the devices. This allowed to get an expedited IRB approval due to the exemption of informed consent and parental permission (IRB document included in Appendix B). Additionally, we took observation notes about student behaviors and social interactions during the whole mini-course, to the best of our ability considering that we had to facilitate the experience at the same time.

5.3.2.1 Participants

We visited the Franklin Institute six times in total within a period of two months (December 2016 – January 2017). We had 80 junior high-school students (11th grade) from the Science Leadership Academy in Philadelphia participate in the mini-course. During two of the sessions we faced network issues, which greatly affected the experience, and eventually engagement, of the students. We opted not to hand out the iPads the second time, since we noticed that this creates more frustration and annoyance, with students appearing to lose interest to participate within minutes, by diverting their attention to other task-unrelated activities. Consequently, we are missing gender data for this group consisting of sixteen students. For the remaining 64 students, we had an equal number of 32 boys and 32 girls. No other demographic data were gathered.

5.3.2.2 Setting

We were assigned to present the mini-course on the third floor of the museum, in the Sir Isaac’s Loft classroom. This was a large space with ample room to separate the game experience and the after-game activities. Similar to our other studies, the game was projected on a large 16:9 space of a white wall, and students sat at a distance of around 4 meters, with players sitting slightly closer (see Figure 5-24). A poster explaining the mini-course goal and technology was placed next to the projection and was used to explain the theme of what was about to be experienced. We used a Dell XPS laptop with a powerful enough processor and graphics card to run the real-time game engine. Wireless Xbox controllers were used as interaction devices for the players and Apple iPad 2 Air devices for the audience.
The after-game process board activity consisted of the printed board placed on two tables, and ten 3d-printed machines (steam engine, boiler, mill, press, water pump, oil pump, and Laval separator) and devices (platform scale, oil tank, and table). All models were encased after the first two sessions to protect them from handling and manipulation by the students (all model images can be found in Appendix B). The remaining artifacts used in the process game were the following: three jars of water, one jar of olive pomace, one jar of pure olive oil, one jar of mixed olive oil, one jar of olive paste, one jar with olives, one jar with the label ‘steam,’ one with the label ‘motion,’ a piece of old fiber sack, a rubber belt, and a plastic pipe. All items were placed on a table across or next to the process board (see Figure). The items used for the last stage of the mini-course (most of them shown in Figure 5-23), were placed on other tables around the room.
5.3.2.3 Procedure

School groups participating in our mini-course were part of a larger group of 120 students visiting the museum in the context of the *Wednesdays @ The Franklin* educational program. The person acting as a liaison between the museum and the school recruited the groups and guided them to our classroom before the start of the mini-course. Students were greeted and randomly sat, in no suggested order, in the auditorium-style seating space positioned across the screen. We asked them about their knowledge of the topic being presented and introduced them to the subject—steam-powered production of olive oil—using the poster next to the screen. We then asked them to raise their hand if they were good team players and experienced in playing 3D games. We randomly picked two of them (trying to have one girl and one boy), and after seating them in front of the audience, we explained the two forms of interaction (Xbox and iPad) and how they should collaboratively troubleshoot problems in the game in order to succeed and produce olive oil.

We then started the game and, after the brief intro was finished, we guided them into solving the first problem, attaching a belt to one of the machines. Similar to our last experiment, this was thought to be the best candidate for the practice session, including a video explaining motion transfer with the use of belts and pulleys, an iPad question about how machines were powered, and a collaborative action between players in completing the task. After this task was completed successfully, we carried on to facilitate the interaction by helping players when they...
were stuck, prompting the audience to participate verbally and justify their choices, and encouraging collaborative problem-solving at all times. Occasionally we took notes about student engagement and whenever there were any notable problems or events (e.g., switching of players). When the game was finished, we notified students about receiving a certificate with their accomplishment and allowed them to go on a short break.

When students returned to class, they gathered around the process board, where we split them into four groups (one for every stage of the process). Assignment was done based on free choice (i.e., whichever part they thought they remembered the best), unless they had no preference. They were instructed to read through the labels in their assigned stage and then look for the desired object(s) on the table. Groups were given approximately 10-15 minutes to finish this assignment and then they were asked to present and support their choices. Once more, notes were taken regarding the interactions and general attitude of students during this stage. When finished, and before proceeding to correct any wrong placement of items, we took a photograph of their finished process board.

Finally, depending on the remaining time before the end of the mini-course, we displayed the remaining artifacts and engaged the students in a dialogue about which machines operated using the exhibited principle and where they have seen it in the game. As an example, students were presented with the two different pumping systems (i.e., the items shown at the bottom of Figure 5-23) and were asked “which machine in the game operates with the principle illustrated by each artifact and why?” Although we initially planned to assign student groups to different workstations inspecting the items by themselves, we found this inappropriate both for practical reasons (e.g., the mini steam-engine was using real fire to heat the water) and for accommodating the observed lack of motivation to participate expressed by some of the students.

### 5.3.3 Observations

Findings from the case study were mainly observational due to the real-world perspective we wanted to acquire and the challenges of gathering data more systematically, considering our facilitation of the experience at the same time. All six groups participating in the mini-course finished the game, although only 47 students out of the 80 total (59%) got to experience the iPad interaction, due to network issues in two of the sessions. Audience members in these two sessions were encouraged to participate verbally, but this proved rather challenging especially for the first
group of the two, where students had the iPads in their hands and tried to use them. We had 10 boys and 2 girls participate in the game as players. It took groups 40.93 mins on average to finish the game, with 47.38 mins for the slower group (13 students) and 37.18 mins for the fastest group (17 students). Moreover, all groups played the process board activity, although in different degrees of involvement, but not all of them got to experience all after-game activities. This was mainly due to time constraints imposed either by a delayed arrival of the group, a prolonged break, and/or a longer time in finishing the game/after-game activity. In most cases, we inquired about the use of the props and the principles they exhibit, but in only half of the groups we got to exhibit the mini steam-engine. Students in some of the groups were also asked to provide feedback/comments about the game and how to improve it, as a means to involve them more in the experience as evaluators/co-designers.

As a results of the aforementioned complications, which are inevitable in a real-world situation, we observed a wide range of engagement levels between the sessions. A common pattern we observed is that in most groups there were a few students that were fully immersed in all the activities (usually 3-4 students), while the majority alternated between on- and off-topic tasks, which was detrimental to their understanding of the process. Off-topic tasks included playing with a mobile phone, talking with a peer, or standing up and wandering around. We even had an instance where a student-player was checking his mobile during the video clips. It is in cases like this that the benefit of group collaborative effort is even more apparent, since students from the audience were jumping in to suggest what needs to be done and facilitate the progress in the game. In the absence of such a setting, student-players could wander around the factory with no clear goal or indication of how to proceed, with a clear negative impact on their learning, as was observed in the “quiet” groups during our third experiment (where interventions by the facilitator were more controlled compared to the case study).

5.3.3.1 In-game Engagement

In general, it was challenging to make inferences about the students’ degree of understanding during the game, as some of them were more vocal than others in following the process. We prompted students to participate and respond to questions displayed on the screen or problems occurring in the factory, but we cannot make solid arguments about how much these specific students learned from the game. Our only evidence is participation in the after-game activity (our
main assessment tool in this informal study), which is discussed below. As far as in-game attitude, we provide some examples that indicate the engagement of students, and especially the audience, with the game content.

A very common practice we followed during the facilitation of the game was to inquire about alerts and problems in the factory. As a typical example, we were asking why the boiler alert did not go away, even after they loaded the boiler with fuel. In the following excerpt, a boy responds to such a prompt in the first session (designations of F for facilitator, P for player, A for audience, and B/G for a boy or a girl are used throughout the examples):

**Example 1**

- F: *Good, the solid fuel is in there, but the boiler is still not on; why is it not on?*
- AB: *You need to put it on fire… get the matches!*

In this case, the boy shouted out the response only milliseconds after I finished my question, clearly indicating that he had realized that the alert (about the boiler not working) did not go away and had also identified that there was a box of matches on the table in one of the factory rooms. He might have realized that this was the next step due to the majority of votes for response “Burn some kind of solid fuel” noticing you have to burn the fuel (bold used here for emphasis), or simply by recalling the information presented in the video a few minutes before. It was not readily apparent how the boy figured out the next step, but the important observation for us was that he could contribute to the progression of the game, as one of the players followed up on his prompt right away and completed the task (of staring up the boiler) only within twelve seconds after the initial action (of loading the boiler with the fuel).

Another benefit of the large group setting as experienced in the case study, was the alternation of players. Either voluntarily or through the facilitator’s prompt, players could surrender control to an audience member and switch roles on the spot. This could relieve issues pertaining to a sense of decreased control/involvement, such as the one noted by a girl participant in the last session, exclaiming in a disappointed voice “I thought we were playing!” It can also remedy situations of uncooperative players, such as a boy player in the fifth group, who was acting in a selfish manner disregarding suggestions by the audience. By switching him with someone else not only improved the engagement of the whole group, but also allowed one more student to experience a higher level of control and appreciate the educational experience. This particular
student became much more involved in the whole process, eventually commenting that this was his second best course in the museum after cooking, just because he loves to cook.

5.3.3.2 After-game Activity: Process Board

The performance of the students in the after-game activities varied greatly, once more, between sessions. Table 5-2 includes a summary of the performance (i.e., errors in placing models and artifacts on the board) by group and for each stage of the process being presented. In most cases students who attended and participated actively in the game were involved in the process board activity and could identify some principles in the final activity. Also, in some cases the more active students took the initiative to complete the whole board, either by themselves or by helping the ones assigned with a specific stage. We also noticed that the smallest group #4 was more focused and maintained their engagement with the process board for a longer time. Larger groups were harder to manage, mainly because the uninterested students were distracting others who could potentially contribute to the activity.

<table>
<thead>
<tr>
<th>Group</th>
<th>Students</th>
<th>iPads work</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>17</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>#2</td>
<td>17</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>#3</td>
<td>16</td>
<td>No</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>#4</td>
<td>6</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>#5</td>
<td>13</td>
<td>Yes</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>#6</td>
<td>11</td>
<td>Yes</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 5-2. Process board performance of groups according to errors made per stage of the process.

Another interesting observation was that students who revealed an increased comprehension during the after-game activity were not necessarily the players, like the previous studies have indicated, but rather the ones who were intrinsically motivated to be engaged in the game. Gauging students’ motivation to participate in most cases revealed either an interest in the topic (e.g., a girl audience member was ecstatic when was offered an olive as a sample), or game play itself (e.g., the boy player we mentioned earlier, who appreciated the game experience after replacing the original player). In both of these example cases, the students mentioned were among
the ones who participated and contributed the most in the after-game activity and could recall the most information. Such observations suggest the importance of finding relevance and matching interests for increased motivation, participation, and eventually learning.

It is valuable at this point to mention the types of activities that students were involved in during the process board activity. These were attitudes we noticed in general and although no specific behavior is unquestionably conclusive of learning, they reveal the interest of some students to participate and get involved in the learning process. Furthermore, similar observations have been used in coding the interactions of visitors in museums and identifying the types of visitor talk that can contribute to learning (e.g., Allen, 2002). Table 5-3 summarizes these attitudes, including a brief description and in some cases an example from students’ interactions with the artifacts.

<table>
<thead>
<tr>
<th>Attitude/Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspecting artifacts</td>
<td>Student inspects the models or artifacts</td>
</tr>
<tr>
<td></td>
<td>E.g.: <em>These are 3d-printed? These are amazing! Wow!</em></td>
</tr>
<tr>
<td>Reading instructions</td>
<td>Student reads instructions on the board</td>
</tr>
<tr>
<td>Naming object</td>
<td>Student names a machine or artifact</td>
</tr>
<tr>
<td>Seeking an object</td>
<td>Student looks for an object s/he thinks should be placed on a placeholder</td>
</tr>
<tr>
<td></td>
<td>E.g.: <em>We need the motion jar! Who has the motion jar?</em></td>
</tr>
<tr>
<td>Recalling information</td>
<td>Student recalls information from the game and/or the videos</td>
</tr>
<tr>
<td></td>
<td>E.g.: <em>It was the wrench thing we had to do, remember?</em> (looking for the belt)</td>
</tr>
<tr>
<td>Explaining operation</td>
<td>Student explains how something operates</td>
</tr>
<tr>
<td></td>
<td>E.g.: <em>This is operated by the steam</em> (pointing at the engine)</td>
</tr>
<tr>
<td>Justifying action</td>
<td>Student justifies his/her placement of an object on the board</td>
</tr>
<tr>
<td></td>
<td>E.g.: <em>You use water because it's a hydraulic press</em> (placing the water on the board)</td>
</tr>
<tr>
<td>Questioning choice</td>
<td>Student questions someone else’s choice/placement</td>
</tr>
<tr>
<td>Seeking evidence</td>
<td>Student looks for additional evidence or confirmation of his/her choice</td>
</tr>
<tr>
<td>Helping others</td>
<td>Student moves to other parts of the board and attempts to complete the process</td>
</tr>
</tbody>
</table>

Table 5-3. Attitudes or activities observed by students during the process board activity.
We will now present more detailed examples of students being involved in three categories of interactions: making claims (naming object, explaining operation, justifying action), challenging claims (questioning choice), and confirmation activities (seeking evidence). These categories have been used to identify scientific reasoning during family engagement at touch-tank exhibits (Kisiel, Rowe, Vartabedian, & Kopczak, 2012) and are in accordance with the National Research Council (NRC) report “Learning Science in Informal Environments: People, Places, and Pursuits” (Fenichel & Schweingruber, 2010) presenting a multifaceted model of inform learning, beyond the assessment of conceptual understanding of scientific material. More specifically, we believe that during our process board activity students were involved in scientific inquiry, exhibiting skills such as experimentation and exploration of ideas, predicting outcomes, drawing conclusions from evidence, and most importantly articulating their thinking through conversation with others.

Example 2 – Making Claims (justifying action)

- PB: This goes here, since the grinder makes the paste (while placing the olive pulp)

Making claims was the most prevalent form of expression noticed during the process board activity. In this case, a boy player is verbalizing his action of placing the item correctly on the board, after identifying the jar with the olive pulp as the product of the grinding process (referring to the mill as the grinder). Although such utterances might not be very sophisticated forms of scientific reasoning, they illustrate that students had some level of understanding of the process presented in the game. These types of claims have been characterized as perceptual talk during work at the Exploratorium on characterizing visitor talk during exhibit exploration (Allen, 2002) and capture the “act of identifying and sharing what is significant in a complex environment.” Similar to our observations, this was the most frequent form of utterances by the visitors that revealed evidence of learning, while exploring an exhibition with a variety of interactive/hands-on and traditional exhibits.

Example 3 – Making Claims (explaining operation/justifying action)

- AG1: You all, the steam is the product of machine A (pointing at the boiler)
- AG2: So that has to go there (placing the steam jar)
- AG1: The motion does something...
5.3 Case Study

Making claims was also expressed through collaborative actions, such as the example presented above. Two girls working at the first stage of the process (powering the factory), were trying to place the artifacts correctly, after having identified the machines. The first girl explains partly the operation of the boiler by mentioning that it produces steam, while the second girl grabs the jar with the label ‘steam’ and places it at the correct placeholder. In this case, AG2 followed up on AG1’s thinking to justify the action of placing the steam right after the boiler as the machine’s output. The discourse continued by trying to identify the use of ‘motion,’ after having recognized that it is a part of their designated stage. The instance exemplifies how group members very often reached a consensus and proceeded in completing the board, but this was not always the case.

Example 4 – Challenging Claims

- AG got the jar with mixed oil and was placing it at the wrong place on the board
- PB: *No, it goes here after the squeezer* (grabbing it and moving at the right place)

In many cases we observed that students disagreed and challenged its other’s opinions and choices in placing the items; challenges appeared as disputes of a claim. In the example above, PB was trying to help other teams after finishing his designated part (i.e., powering the factory). While standing in front of Stage 2 (grinding), he noticed a girl placing the jar with mixed olive oil as a product of the mill. He intervened by explaining that the mixed oil comes out of the press (referring to it as the *squeezer*), moving it to the correct placeholder at the next stage. In this case there was no counterargument and the suggested solution was accepted as correct.

Example 5 – Challenging Claims

- PB: *Machine A used to, used to provide...* (reads instructions)
- AB1: *Oh, yeah, grinds the...* (placing the mill in the placeholder)
- AB2: *No, that's way late, that's... you had to...*
- PB: *No! You see, this goes here and that goes there* (moving the mill away and placing the boiler)
- AB2: *Yeah!*
- AB1: *Oh yeah, it's that box* (talking about the boiler)
There were, however, other instances where students were involved in a discourse about the correctness of some action performed by one of them. In the example above, three students were working together in Stage 1 (powering the factory). One of them was reading silently the instructions and a second one, holding the mill, incorrectly recalled that the machine in question was the one that grinds (the olives) and proceeded by placing the mill in the placeholder. Both of his peers questioned his choice; one of them saying that grinding was way later, while the other one proceeding to rearrange the models on the board. After placing the boiler in the correct place, as requested by the instructions, the student who performed the wrong action realized that this was the correct machine, recalling (probably from the video) it had a box shape. These more complex interactions between students and the activity’s artifacts are believed to demonstrate the type of social and distributed nature of scientific reasoning occurring during museum visits (Kisiel et al., 2012) and are in the core of many of the learning theories we investigated during our literature review (see Section 2.1.1), such as distributed cognition and sociocultural learning theories.

**Example 6 – Confirmation Activities**

- AB: *We need the oil, guys!*
- AG1: *I think... I think this is the oil* (grabbing and bringing the olive oil)
- AG2: *Are you sure this isn't it?* (addressing the facilitator while picking the mixed oil)
- F: *This is mixed oil, so it's not the green one, it's the mixed one, right?*
- AG1: *Yeah, this is it!* (placing the olive oil on the board)

There were many cases where students were seeking evidence regarding their assumptions of what goes where, usually in the form of seeking consent from the facilitator or placing items on the board and checking their correctness with their peers. In the last example, three students are trying to complete the last stage of the process (separation). A boy shouted that they needed the oil and a girl went to the table and grabbed the jar with the mixed oil. At the same time a second girl grabbed and inspected the pure olive oil, while asking the facilitator if that might have been the correct one. After receiving an explanation about the appearance of each oil, AG1 confirmed her hypothesis and proceeded to place the correct item on the board. Once more, using the artifacts as cognitive tools, the students tried out their hypotheses by inspecting/manipulating them on/off the board and sought confirmation by negotiating/testing their actions with their peers and the facilitator.
Example 7 – Scaffold learning

- AB1: *What’s the first machine?*
- AB2: *What’s the substance?*
- F: *You are using this to heat up what, and produce steam?* (lifting up the pomace)
- AB1: *You’re using this...* (pointing at the pomace)
- F: *What are you heating?*
- AB1: *...to heat up the, eh...*
- F: *What? I told you, you’ve seen the boiler; I told you that’s how boilers are working, even in real life.*
- AB1: *Yeah, the steam...*
- F: *What do we heat up to produce steam?*
- AB1 & AB2: *Water!*
- PB: *Now, we need the water*

In a way to support students’ understanding of the process and concepts involved, and seizing the opportunity of facilitation, at some points we scaffolded the completion of the board through inquiry. In the example above, we are guiding the students in completing the first stage by asking them questions regarding what they saw in the game and assumed prior knowledge (e.g., on steam created by heating water). Students were guided into thinking about the operation of steam production as was presented in the game (“I told you, you’ve seen the boiler”), but also from personal experience in other contexts (“I told you that’s how boilers are working, even in real life”). This was a common practice we followed especially during the walkthrough of the process, after all students were done, in order to remedy misconceptions and construct the correct process on the board (see Figure 5-26 for a completed board from one of the sessions).

A final observation regarding the process board activity was that many students failed to follow our suggestion about how to complete the board. Instead of reading the instructions and then identifying the appropriate item, they were rushing to the table and picking random items with no clear indication of where to place them. We noticed this behavior especially prevalent among the students who were more hesitant or unwilling to participate in the activity; a fact that explains the large number of mistakes for group #5, who seemed particularly disinterested in the topic.
5.3.3.3 After-game Activity: Principles

Regarding the final activity about identifying the principles of various artifacts, we could not really draw any useful conclusions as in most cases we either skipped or rushed through the activity due to time constraints. In the few cases we inquired about the principles, most of the students could not make the connection between the artifacts and machines in the factory. In very few instances, some students tried to recall information from the videos (where the mechanics of the machines were explained), but could not clearly articulate the concepts presented. As an example, a very active girl-audience member from the third session attempted to explain the operation of the pump system (see Figure 5-23 bottom-right), using terminology such as high and low pressure pistons. However, we realized that such material is beyond the curriculum of early high school and most students struggled in understanding and recalling mechanical parts and concepts presented in the game and the videos.

Finally, the mini-steam engine (see Figure 5-23 top-left) was the highlight of the mini-course, during the three times we got to exhibit its operation. Students gathered around the table
where the engine was placed and stayed there until the end of the course. In many cases they volunteered to help by either filling up the boiler with water or heating up the water in the microwave oven. They were particularly interested with the live demonstration of a working model and were actively asking questions, more than any other time during the experience. Even students who were disinterested during the game and/or the process board were attracted by the model and were engaged in the demonstration. As an example, a girl-player in the last group, who expressed no interest on the topic when asked at the beginning, left the room very excited commenting that this was by far the best course she attended at the museum.

Overall, performance during the game and after-game activities was satisfactory for students who were motivated to participate, either due to personal interest on the topic or because they found the activity itself rewarding. Motivating factors we observed included: a) a personal interest in the subject matter, or what Allen (2002) refers to as life-connection in her analysis of visitor talk, (e.g., a French boy who mentioned that his grandfather owns an olive press factory in South France); b) an interest in the means of presentation (e.g., the boy player mentioned earlier who found this most rewarding because he loves games); c) an appreciation in some part of the content (e.g., a boy player who expressed his appreciation for manual manufacturing due to “having control of the process”); and d) an appreciation of some other part of the experience (such as the girl player who got excited with the models and the mini steam engine). We consider all these factors to have significant implications for increasing the engagement of student groups with (digital) games in museums and discuss them further in the next section.

Finally, at the beginning of each session we gauged students’ awareness about the theme of the course. We realized that most students did not know why they were in the room and even the ones who knew, did not seem to have been offered a rationale about the choice of the topic. They also had not chosen to participate in our mini-course and were randomly assigned either by their teacher or the museum’s program coordinator. Moreover, most of them did not express any particular interest about the topic, when presented with an overview of the subject being presented in the course. We believe that these three factors had an apparent impact on “free-choice” learning, as well as their interests and expectations being satisfied from the specific visit, significant factors affecting engagement and learning as expressed by the museum literature and the Contextual Model of Learning (CML) used in our framework.
5.4 General Discussion of Experiment III & Case Study

Doing a high level review of the two studies, we noticed quite a few differences regarding the students’ attitude and eventually engagement in the game. Students in our formal experiment in public schools were much more disciplined and focused on the experience compared to the ones in the museum. There are many reasons that could potentially explain this a difference. First, it might have been a setting effect, with students in schools participating in the game between classes and under the supervision of their teacher, while the museum one participating in an out-of-school activity without the presence of an actual authority. We consider this the most probable cause explaining the difference in attitude between the two populations, a fact that we also noticed in our comparison of the first two studies. We strongly suggest that the setting had a significant impact on the lead motive orientation of the students (Hedegaard & Fleer, 2013), with school students’ behavior being affected by a motivation to learn, while the museum ones being guided by a motivation to play.

This fact by itself should not have affected our findings significantly, considering that our game was developed for informal learning contexts and play is part of the experience. A second factor affecting the difference in attitude was most probably the age of the population. Up until now we have been testing our system with middle school students (6th-8th grade, 11-14 years old), whereas in the case study we had junior high-school participants (11th grade, 16-17 years old). This 2-5 years of difference can have a dramatic impact on how adolescents interact socially both with each other but also with adults. This is especially true for junior students in high school, who compared to their middle-school selves with a very fragile self-esteem, are trying to redefine their identity by forming favorable peer relations (Kinney, 1993). This can be commonly manifested by appearing disinterested in school stuff and joining cliques with a common attitude towards other student groups or authority figures inside and outside of school.

Moreover, the location of the studies might have played a considerable role by itself. Both schools in our third experiment were located in small towns, while the case study happened in a major metropolitan area. This fact might have implications affecting student behavior, such as upbringing practices in regards to discipline, which in a busy urban environment might be more relaxed; the prevalence (or allowance) of technology use in an educational setting, with city children getting an exposure to mobile devices in a younger age; and an effect of the society’s cultural
consistency, with the city being much more multi-cultural than the sub-urban locations. An example of how this might affect learning can be found in literature examining the difference between Euro-American and Indian or Afro-American children (Shade, 1989), with the former being more drawn to objects and the accomplishment of tasks or the acquisition of content (field-independent learners), while the latter being more drawn to people and the social traits of the environment (field-dependent learners). Considering the multi-cultural consistency of the classes visiting the museum that we observed, one can understand how our instructional practices might have been perceived differently by students with different ethnic and cultural backgrounds.

All the factors mentioned above in conjunction with the largely different experimental design and scope of each study (i.e., a formal assessment vs an informal case study), render any credible comparison, especially about learning, extremely presumptuous. We can still discuss about levels of engagement we perceived during the two studies, even though we only recorded self-reported game experience outcomes (a superset of engagement/immersion) during the third experiment. Disregarding these scores for a moment, which sometimes can be biased towards the positive side especially with younger participants (Read & Fine, 2005), we noticed an almost equal level of student engagement with the game among the two studies. Differences derive mainly from distractors like the use of smart phones during the case study, which we did not notice in schools (probably due to mobile device use restrictions).

Audience members were mostly paying attention to the game and contributed occasionally to its progress, although we did notice a slightly higher percentage of on/off-task switching behavior for the older students in the museum. This has also been found to be the case with other collaborative activities in museums, i.e., increased risk of off-task behavior with a companion (Packer & Ballantyne, 2005), an effect that seems to be magnified in larger groups. Checking use of the iPads, we did not find any difference regarding the number of choices students made or the number of missed actions, between the two studies. The duration of the game was significantly increased in the case study, 40.93 mins compared to 28.02 mins ($M_{\text{dif}} = 12.91$ mins), which was expected considering that we added the video clips in between the tasks, also freezing any action for the players, and added one more task with audience interaction (i.e., an ACTION task). Game score was included for motivational purposes only and was deemed irrelevant in assessing either engagement or learning of participants.
Chapter V – Audience Interaction

Regarding engagement in terms of the social interactions between group members, again we did not notice any considerable differences between the two experimental settings. The large sample size of the school experiment allowed us to experience a wide range of group behaviors, from very vocal and—presumably—engaged classes to very quiet and—seemingly—disengaged ones. Nonetheless, interviews with the middle school teachers revealed instances of groups exhibiting an uncommon behavior during the game as compared to their classroom attitude; i.e., typically silent groups being very vocal during the game or vice versa. It is unclear how that change might have had a positive impact on students’ learning or not, as our analysis on within-group social interactions (see Section 5.2.3.4) did not provide any insights. On the other hand, the sample from the museum was too small to draw any credible conclusions, although we did notice that our smaller group (with only six students) maintained a higher level of engagement throughout the whole mini-course. However, their performance at the process board activity was on par with most of the other groups (see Table 5-2), even with considerable scaffolding. It might be interesting to note that the first two largest groups (17 students each), revealed the least errors in the board activity, which supports our finding about the correlation of group size with increased learning outcomes in the school experiment.

In terms of learning, there was evidence in both studies of conceptual improvement about the complex process being presented. In the school study it was mostly in the form of quantitative analysis of quiz scores, while in the museum study it was qualitative analysis of our observations. Examining both findings in parallel, it is hard to conclude in what level the higher level of involvement of the audience or our revisions for the mini-course had an impact on the learning outcomes. However, we consider that our intervention was successful in engaging students with the game and—in most cases—socially, but also significantly increasing their understanding about complex material, which in many cases was beyond their academic level (e.g., first time exposure to centrifuge power for 11th grade students). Finally, we can testify about the beneficial role of facilitation in our case study, which enabled students to progress in the game without many moments of frustration, also alleviating negative effects on audience engagement due to increased feelings of disconnect. Similar instances observed in the school study, in which our guidance was much more controlled, can explain the higher levels of challenge and tension experienced mainly by the players, but also the disassociation of learning gains between players and audience, observed especially in the high involvement condition.
5.5 Limitations of Studies

Although we carefully designed both studies to identify effective techniques for audience interaction, there are some inherent limitations which should be taken into account when considering our results. First and foremost, learning in informal contexts cannot be measured simply from the immediate outcomes, since a museum visit is mainly a trigger for a long-lasting learning process. The pre/post-test design used as an assessment tool in our studies bears the inherent limitations of measuring short-term learning outcomes, specifically focused on conceptual change. However, deep conceptual change cannot derive by a simple visit to a museum, but is rather a long term process that involves other activities outside the museum space (Roschelle, 2007). Ideally, learning in museums should be evaluated using sociocultural theory; i.e., understand how learning unfolds through the interplay between people acting in a social context and the “mediators” (i.e., discussions, tools, symbol systems, etc.) employed in these contexts (Schauble, Leinhardt, & Laura Martin, 1997). This was partly our effort in our case study analysis of the students discourse incidents, but is lacking the thoroughness of similar work about learning in museums. For example, Allen (2002) tried to address the richness of learning opportunities during museum visits, by identifying and categorizing visitor discourse in five categories of “learning-talk”: perceptual, conceptual, connecting, strategic, and affective. A more elaborate investigation should have included this type of analysis, which was infeasible for both of our studies either due to the difficulty of capturing the discourse between 15-20 students, or due to the lack of permission for video/audio recording the sessions.

Furthermore, engagement was only partially captured by the GEQ, as there was so much more happening during each game session. In all our experiments (besides the case study), we have been mostly focused on the measured “products” of the experience, mainly learning scores and self-reported game experience measures. However, as Perry (2012) suggested, “both process and product, both engagement and outcomes, are essential and intertwined components of museum visits.” To address this gap in our latest experiment, we attempted to conduct audio analysis of the recordings and juxtapose the results with logged game data on a temporal scale (see Section 5.2.3.4), as a means to identify behavior cues and patterns that might explain the connection between social engagement, game performance, and learning gains. However, the quality of the
recordings and the setting (i.e., multiple voices overlapping in a large space) prevented us from getting usable results.

Finally, generalizations about culture should take into account the locality of the experiments. We have made rough interpretations about the differences we found between our US and Greek sample, as well as our urban and sub-urban/rural environments, but results cannot be generalized for the whole population of each culture. More subtle differences, such as the exact geographic location regarding proximity to a metropolitan area, climate, and ethnic diversity can affect exposure to educational opportunities and eventually interpretation of findings. We did try to take into account such subtleties when interpreting results in Study II, as well as our last two studies, but this does not imply we have captured the full spectrum of the student population’s diversity. Similarly, differences in socioeconomic status (examined in the third experiment) need serious attention as this is, too, a continuum that greatly varies based on location and cultural/ethnic background, and results can only be interpreted in the context of the specific sample presented in each research study.
Chapter 6

Conclusions

As we described in the introduction, our main motivation to conduct this research was personal experience in working at an interactive museum with a large number of school-age student groups visiting the space. We noticed an unexplored opportunity to harness the social interactions of student groups over and with technology, an observation which was largely confirmed after a thorough review of related work on available group interaction technologies. Based on our extensive investigation of the literature, we developed a conceptual framework combining serious games and virtual environments with the Conceptual Model of Learning (John H. Falk & Dierking, 2000), as a means to support student engagement and learning during school group visits to informal education contexts. Our conceptual framework guided the development of our research questions, which aimed at investigating how different elements of the framework (e.g., autonomy or level of control, interactivity, facilitation, motivation and expectations, etc.) can potentially affect the group playing/learning experience.

We then designed a computer simulation game, called C-OLiVE: Collaborative Orchestrated Learning in Virtual Environments, supporting initially small group collaboration (up to three players) and then simultaneous interaction of a whole classroom. We ran three full scale experiments with 710 middle school students in schools, summer camps, and a museum, in two largely different cultural contexts (US and Greece). We concluded with a case study in a science museum, presenting a mini-course about the subject matter, experienced by 80 11th grade students. In the following paragraphs, we present a summary of our finding ordered by research question and the hypotheses we have made for each question, based on the literature and our own experience. We then revisit the conceptual framework for a high-level review of lessons learned and conclude with a list of design guidelines for improving interactive group experiences in museums.
6.1 Summary of Findings

In this section we revisit each one of our research questions (see Section 1.3) and summarize the ways that our experimental findings have shed light to each one of the questions. Our hypotheses are used as the basis of our presentation and we also provide information about what extra we have learned from the work conducted.

RQ1: What is the effect of the level of interactivity on learning in a gaming, collaborative VE (CVE) for more than two collocated participants?

The main goal of this research question was to advance understanding on how the level of interactivity affects learning, within small and large groups working together while playing a 3D computer game. This was our overarching question, which we tried to address one way or another during all our studies. The diagram in Figure 6-1 illustrates our conclusions mainly derived from the first two experiments, conducted with small groups of middle school students. Quotes from after-game interviews are presented as anecdotal evidence of the quantitative findings.

Figure 6-1. Summary of findings for RQ1 (S indicates number of study and P1/P3 the experimental condition).
**H1: Higher levels of interactivity will afford greater learning gains.**

Our overall finding was that higher levels of interactivity can improve learning if the game design promotes equal interaction opportunities and students can cope with the complexity of the game/content. In our first study there was a clear association of learning with the level of interaction, with students participating in the three-player (3P) collaborative condition revealing higher learning gains. This finding was revealed from our path analysis only when other experimental factors, such as game experience and social presence, were taken into account. Such a result justifies our overall hypothesis—illustrated in our conceptual framework—that learning can be improved by supporting students’ engagement both with the learning material but also socially. A very frequent comment by students having control of the game in our 1P condition was expressing their preference to be able to get help by collaborating with a peer.

Nonetheless, running a very similar experiment with a population with a largely different cultural background, revealed that simultaneous, unfacilitated interaction of more than one participant can have a detrimental effect on learning. Our study in Greece, where we substituted the fully passive condition with a facilitated one from an expert guide, indicated that such a mediation can alleviate problems arising from the increased cognitive demands of complex multi-player learning virtual environments. Such findings are in line both with cognitive load theory (Mayer & Moreno, 1996; Sweller, 2005), but also critics of fully unguided, discovery-based learning with serious games (Clark, 2007; Kirschner et al., 2006). The challenging nature of the experience was captured both from our game experience assessment, where students in both interactive conditions expressed high levels of challenge and tension, but also from many comments by students during and after the game, even for the ones without direct control in the game (e.g., the one made by a non-controller player in the 1P condition shown in Figure 6-1).

Another factor regarding learning that should not be underestimated, is the effectiveness of C-OLiVE in speaking in the language of the learners. Most participants felt extremely comfortable with the game and there were apparent indications that they forgot they were learning something. Such indications include comparison with conventional forms of instruction, as indicated by the comment made by a controller-participant in our second study (see Figure 6-1), but also comments from teachers who praised the game as an effective instructional approach for engaging the whole classroom, even in a school classroom (in the third study).
RQ2: What is the interplay between level of interaction, game experience, social presence, and learning during within-group collaboration in physical space?

The main objective of this question was to deepen our insights on how all these measures are connected in the context of collocated collaborative play. Once more, this question was mainly addressed with our first two studies focusing on small group interaction in various settings. The summary of the findings is illustrated in Figure 6-2 below.

**Figure 6-2.** Summary of findings for RQ2 (green cloud has a positive impact, while orange a negative one).

**H2: Higher interaction levels will increase game experience and social presence, positively affecting the learning outcome.**

This question has been partially addressed in our previous question, since learning has been found to be correlated and influenced by the other factors, as shown during our path analysis. More
6.1 Summary of Findings

specifically, there was an apparent effect of the level of interactivity on game experience, with students participating in more interactive conditions expressing improved game experience. This was manifested either with increased positive affect (i.e., in terms of interest and attention) in both studies comparing 3P to 1P participants, or decreased negative affect (i.e., less boredom) only in the first study, in which also GE as a whole was found improved for the 3P over the 1P condition. The path analysis did not indicate a significance in the causal connection between interaction level and GE, so we cannot make a strong argument about such a relationship. However, when group learning was mediated by an expert guide, positive measures (such as positive affect) were improved and negative ones (such as negative affect and tension) were mitigated, as compared to unguided 3P participants. Since passive/facilitated participants in the second study revealed improved learning gains, this might explain how facilitation can mediate interactive experiences for student groups involved with digital learning games. We can only extrapolate, though, that facilitation could improve learning gains in interactive conditions too since during all three studies we followed a strict intervention schedule, which intended more to keep students on track rather than facilitate their understanding with the material presented.

Regarding social presence, we have evidence (from the path analysis) about the causal connection between social presence and game experience (a highly significant correlation) and between social presence and learning (a significant correlation). Nonetheless, we cannot ignore that although interactive conditions in the second study afforded greater feelings of interconnectedness between participants (both in terms of behavioral involvement and SP overall), these students revealed significantly decreased learning gains. We have two interpretations regarding these contradictory findings from the two studies. First, we hypothesize that the negative feelings (i.e., jealousy, shame, and shyness) expressed by many of the student players participating mainly in the 1P condition compromised their social gaming experience and affected learning (see comment by a controlling player in the P1 condition in Figure 6-2). More importantly, learning is a complex construct and cannot be attributed to one dimension of the game experience; other factors affected the students’ ability to cope with the demands of the interactive conditions in the second study, which explains to a larger extent their poor performance in the assessment.

We should not, however, underestimate the value of simultaneous collocated gameplay of a small group for enhanced engagement, which is probably the most desirable goal of a museum. Both studies revealed increased levels of game experience (or some of its measurable components)
for the interactive conditions, as well as increased social presence deriving from the within-group social interactions demanded for performing most of the tasks. We should emphasize here that results are to a great extent tightly related to the game design, and different design choices might have revealed different outcomes. Notwithstanding, many of our participants, even the ones who did not perform well in the game, asked about the opportunity to play the game at their own pace at home, which can be regarded as an indication of positive impact in terms of engagement.

**RQ3: What is the effect of culture, prior knowledge, and the style of information presentation (facilitated or not) on learning using a gaming CVE in a museum-type setting?**

This was a rather complex question, in which we attempted to address many attributes of our conceptual framework, by visiting a museum and running a similar study with a different population in terms of culture and expected prior knowledge on the domain. Results presented here are by no means conclusive, but serve as first step to further our understanding of how such complex interactive experiences might be perceived and affected by students with a different sociocultural background. We need to emphasize that this was the first study—to our knowledge—that attempted to address the differences in group interaction with digital games across cultures.

![Diagram illustrating the relationships between Prior Knowledge, Culture, Facilitation, Learning Style, Collaboration Behaviors, and Game Experience](image-url)

*Figure 6-3. Summary of findings for RQ3.*
6.1 Summary of Findings

**H3a: Prior knowledge will be a contributing factor to learning.**

Our motivation to visit a place like Greece for our second study had to do with the rich history of the country in olive oil production, the subject matter of our game. We chose to run the study in a museum on the island of Crete, one of the most prolific olive oil producing regions of the country. Despite the assumed increased prior knowledge of the students on the topic, learning gains in the exact same quiz were significantly lower than the ones recorded in the first study in the US. Weirdly enough, students who reported the highest level of perceived prior knowledge, revealed the lowest scores in learning improvement (see Figure 4-11). We believe that this can be attributed to a number of factors, the most important of which are the **misconceptions** of students’ understanding about the process, which can be a serious hindrance in learning new facts which seem contradictory to existing knowledge (Roschelle, 2007). This fact combined with the cognitive challenges of students to cope with the game, largely explain why culture-based prior knowledge was not found to be a contributing factor to learning. This also explains why facilitation proved to be beneficial in a great extent for this specific population (see H3d below).

**H3b: Cultural differences will affect the learning outcome in an unpredictable manner.**

Differences in culture were assumed to play a role in how students perceive and interpret the information presented in the game. We intentionally did not make a directed prediction here, as we were unsure of the implications of culture on learning. We found that culture affected the outcome mainly in terms of learning styles and collaborative behaviors, with other factors being of less significance. Culture-specific learning styles were manifested as differences in exposure to discovery-based learning opportunities and ability to cope with complex digital environments. Students in the first study seemed to be more exposed to discovery-based learning—as being part of a University town with plentiful such opportunities—and also learning through trial and error—a trait of US educational culture, also captured by the cultural dimension of uncertainty avoidance where Greece ranks much higher than the US as a society (Hofstede et al., 2010). Moreover, the difference in school grade between the two populations, with Greek subjects being primarily elementary school students compared to US middle school students, was assumed to have affected their learning performance significantly.

Considering collaborative behaviors, we noticed significant differences in how students behaved in this group gameplay setting, which we assumed was a consequence of both the culture
and the experimental setting. More specifically, students in Greece seemed more socially conscientious during gameplay, attending to their peers’ performance (e.g., trying to help them perform tasks by getting their controller) and involvement in the game (e.g., calling them to do a task in the 3P condition or giving them the controller in the 1P condition). Students in the US study revealed a more individualistic approach, also supported by Hofstede’s (2010) comparison of the two cultures in terms of the individualism dimension, which allowed them to be more focused on performing well in the game. Additionally, we felt that the setting of the experiment in conjunction with the culture, influenced the attitude of the students towards gameplay. Students in schools and summer camps in the US were driven by a motivation to learn and master the game, while the ones in the museum in Greece were more oriented towards better score performance and beating their peers. Performance-oriented students sacrifice learning opportunities by avoiding negative judgment, anxiety, and shame caused by poor performance especially in the face of challenges (Dweck & Leggett, 1988), an effect magnified by the socially sensitive nature of a collectivist society like Greece. On the other hand, mastery-oriented students are focused on (individualistic) learning goals and mostly disregard the manifestation of their abilities in a given moment, feeling pride and pleasure through the effort of acquiring mastery.

**H3c: Cultural differences will not affect game experience and social presence.**

Based on our previous observations and findings regarding the impact of culture on learning styles and social behaviors, but also the different correspondence between age and school grade, it only makes sense how game experience has been affected by cultural differences. The more cognitively challenged, socially conscientious, and antagonistic students in the second study experienced greater levels of challenge, tension, and negative affect during the interactive conditions. What is interesting to note here is that in both studies, students participating in the highly interactive 3P condition expressed significantly higher positive affect compared to their 1P counterparts. This was also confirmed by 1P participants expressing various complaints about the unequal interaction opportunities during the interviews in the first study, regardless if they were controlling the game or not (for an example see comment in Figure 6-2).

As far as social presence is concerned, our findings were almost identical between the two studies. Students from both cultures expressed greater feelings of interconnectedness (i.e., behavioral involvement) during the interactive conditions, while 3P participants in Greece felt
more socially present with their peers compared to the 1P and facilitated/passive conditions. Moreover, students who controlled the game in the 1P condition of the first study, expressed significantly more negative feeling compared to the 3P controlling players. Combining findings from both studies, we can confidently claim that digital games offering simultaneous interaction opportunities for all participants are highly valued by the young populations of the two (sub-groups of) cultures we have used in our studies.

**H3d: Facilitation will help students with lower cognitive abilities and/or weaker game playing experience.**

From discussing the previous questions, it is more than obvious that facilitation of the game experience was found to benefit learning outcomes. The support that an expert guide can provide by involving the students in the experience, pacing her way through the game based on their abilities, can compensate for any incompetency with technology, remedy misconceptions, and alleviate issues with understanding the content. However, because our facilitated condition in the second study was not interactive, we cannot make assertive statements about the impact of facilitation on our proposed group interaction approach. Considering our observations during the case study, where we actually facilitated the students’ interactions, we can suggest that facilitation should be considered seriously during the design of a game like this. It might be necessary to surrender control to the facilitator at times, in order to maintain the students’ attention to the goal of the game, as we have noticed how easy it is to wander off target especially for a larger and older audience that wants to seem independent and omniscient.

**RQ4: How does the level of involvement of a large audience of students affect game experience, social presence, and eventually learning during collocated collaboration?**

This question focused on our main motivation as expressed during the introduction, i.e., *to evaluate new ways of large group interaction in the context of informal leaning*, by examining once more the impact of our intervention on engagement, social presence, and learning. The summary of findings presented below (also shown in Figure 6-4) derives mainly from our third study in public middle schools. Some observations were also drawn from the case study, but due to the lack of data and largely different sample from the rest of our work (in terms of age and environment), it was difficult to use them for validating our hypotheses.
**H4a: Sustained involvement of a student audience will increase game experience, social presence, and eventually learning.**

Students’ learning was not found to be affected when comparing the impact of student involvement between the two experimental conditions—as designed using our testbed application. There was a difference in learning only for the students who did the assessment two days after the game, but this might have been an incidental finding, considering also that most of these students were from a higher-achieving school (see below). A longitudinal study would provide more credible results about the potential impact of high involvement experiences on long-term learning. Moreover, neither game experience nor social presence were found to be contributing factors to learning, as there were no major differences between conditions. Only immersion in the story (an alternative of engagement) was higher in the HI condition, while only behavioral involvement was higher in the LI condition, probably due to these groups being more vocal.

Although our main hypothesis was not supported, we did get the chance to observe two factors that could potentially explain this. First, based on observations of students’ attitude during the high involvement (HI) condition and comments after the game, we noticed that many students felt they were offered inadequate interaction opportunities. This leads us to believe that the difference in
actual involvement with the game (as depicted in Figure 5-2) was not considerably more in the HI condition, in order to sustain student engagement and participation and improve learning compared to the LI condition. Second, students in the audience seemed to offload their participation in the game on the iPad devices more often in the HI condition, as captured by audio analyzing both experimental groups, undermining their social interactions. These interactions, afforded by the physical collocation of participants, were more frequent in the LI condition (also explaining their higher behavioral involvement) and are believed to be a significant contributor to contextual, collaborative learning (J. S. Brown et al., 1989; Chang, 2006; John H. Falk & Dierking, 2000; Lave & Wenger, 1991).

**H4b: Students with direct agency in the game will enjoy the game more, but will not necessarily learn more than the audience.**

Based on the contradictory results from previous research on agency and its effects on learning, we had no strong directed hypothesis. We did find, however, that in our group game setup agency can significantly predict learning by improving both game experience and social presence. This was probably the finding about which we were most confident, since students with a higher agency (the players) revealed significantly better experience than the audience in all GE measures besides tension, while they also expressed a greater sense of social presence in all SP measures besides negative feelings (which were very low for players in both groups). Additionally, student players revealed a highly significant improvement in their understanding about the game’s topic, compared to the audience. Consequently, we can confidently say that higher levels of agency can support learning by improving game experience and social presence, which is the main premise of our conceptual framework. However, we cannot be sure about the role of the audience in our game setup and what might have happened if students were playing alone or in a different arrangement. Similar analysis in our first two studies with smaller groups, splitting the groups in controlling and non-controlling players—basically defining the level of agency—revealed minor contradictory findings (e.g., an improvement in understanding collaborative tasks for 3P participants in the first study only), which cannot be trusted due to the small sample sizes. Furthermore, our analysis on within-group social interactions (Section 5.2.3.4) was inconclusive and further work should be conducted in order to understand the impact of the audience’ interactions in the physical space on the players’ game and learning performance, in a complex social setting like the one researched here.
**RQ4.1: How are involvement level and learning affected by the socioeconomic status (SES) of students, during a collaborative game experience for the whole classroom?**

This added question came up while planning our third study in middle schools and is consequently addressed solely from results of that study (results were included under the diagram representing findings for RQ4, in Figure 6-4).

**H4.1 Students from a higher socioeconomic class will perform better in the game and achieve greater learning gains.**

Our results are based on the analysis of data gathered in two sub-urban schools, with a relatively different population in terms of demographics and education reports. Categorizing the groups attending those schools as either of low or high socioeconomic status (SES), we found that learning was significantly affected by the school location. Groups categorized as high SES, which typically perform better at school, revealed significantly greater learning as compared to the low SES ones, regardless of the condition they participated in. We noticed an indication of greater impact of the high involvement condition for the low SES students only, but this needs further exploration. We should emphasize that SES is a continuum and cannot be divided in clearly defined parts; also, the locality of the school plays an important role on its consistency of different SE class students. This means that running our study in a different environment altogether, such as a rich or poor neighborhood of a big city, might manifest totally different results.

This final observation has implications on the effectiveness of such group experiences, as was noticed especially during our case study. Groups can be much more diverse in a metropolitan setting, not only in terms of SES but also culture and ethnic background. Overall, we noticed there were apparent differences regarding student’s teamwork attitudes, attention, and engagement with the game between middle schoolers in a US small town setting (study I and III), a Greek small town/rural setting (study II), and high school groups in an urban setting in the US (case study). It is difficult to make claims about the cause of the differences without further investigation, as it might be a setting effect, a culture effect, an age/grade effect, or a combination of these. Nonetheless, our observation was that negative social influence was more predominant in the urban high school students, with the majority of them being more easily drawn into unrelated activities, as a means for compliance or to “fit in.” Thus, extra effort has to be taken during game design and facilitation to accommodate for the potential diversity of student audiences.
6.2 Framework Revisited

Since the conceptual framework acted as a guide to form our research questions and design our experiments, we are revisiting it here to identify what we have learned about its validity. Findings from our studies have given us a pretty good understanding about the elements of the framework that can be harnessed for a successful group collaborative experience with a digital learning game. In Figure 6-5 we have highlighted the attributes that we think have been shown to affect engagement and social presence, and in some cases learning, the most during our studies, either through statistical analysis or qualitative data. We discuss the ones we feel hold the greatest promise for achieving the goal that this framework was designed to serve.

![Diagram showing the conceptual framework of research revisited after the studies.](Image)

**Figure 6-5.** Lessons learned: the conceptual framework of our research revisited after the studies (elements with red lines were investigated closely, while terms with blue lines need further investigation).
Agency or autonomy was by far the most decisive factor in increasing student engagement and social presence, and eventually contributing to greater learning gains. As long as students are given full autonomy to control the virtual environment, information is properly displayed, and the challenge level of the tasks does not exceed their skill level, then they get immersed in the experience and acquire the biggest benefits. Social presence seems also to be affected by the level of agency, in terms of eliciting empathy and behavioral involvement through the increased social interactions demanded by co-controlling the fate of the game. Similarly, equal levels of interaction for small group participants can facilitate collaborative problem-solving and understanding of the material being presented. For larger groups, assigning roles with equal agency in the game becomes a challenge, and alternative methods should aim at how involvement of the less active participants should be supported. Involvement in our study was not found to be a contributing factor to either engagement, social presence or learning but we hypothesize that this was due to the relatively small difference in involvement provided by our two conditions.

Social interactions and facilitation were also found to be significant components of improved social and learning experiences during our large-group gameplay approach. Although we have not thoroughly looked into collaborative attitudes of students, our observations indicate that audiences who were more verbally involved in the experience, helping out the active agents to progress in the game, achieved higher learning gains due to their increased engagement and perceived behavioral involvement. Supported by research from museum studies (Perry, 2012), a game experience such as C-OLiVE enables members of visiting groups to stay together and contribute to the solution of a common problem, by encouraging discussion, negotiation, and reflection during problem-solving. However, managing such social interactions during a game activity was found to be challenging, especially for the older students of the case study.

Guidance or facilitation can, therefore, serve the purpose of keeping groups on-task and promoting understanding when misconceptions arise, especially when students are challenged by the nature of the game or the complexity of the material. Although intrinsic motivation deriving from using a game to reach some concept(s) has been touted as an important benefit of both serious games (Thomas W. Malone & Lepper, 1987) and museum visits (Csikszentmihalyi & Hermanson, 1999), we found that this was not the case during our studies. As others have argued (e.g., Kirschner et al., 2006), unguided discovery-based learning, such as the type demanded during digital games, can have detrimental effects on learning gains, if activities are not properly
scaffolded with meaningful interventions and guidance. This was a clear finding from our second study, where students struggled to cope cognitively with the increased demands of the game and the collaboration.

Finally, we only scratched the surface of the part of the framework addressing the implications of the motivation to visit an exhibition, the expectations from the visit, and how much interests, beliefs, and prior knowledge are exploited and/or satisfied by the experience. We found a strong correlation between meeting expectations and satisfying interest with almost all of the measures of game experience and social presence in our second study in a museum in Greece. However, this factor alone was not enough to help students overcome the cognitive hurdles they faced during the game, unless their (passive) game-based learning was facilitated. On the other hand, the case study indicated that not all students had equal levels of motivation and interest in the topic being presented, and most of them arrived with no expectation about their visit. We recognize that our testbed used a very specific topic that might not have been appealing to the majority of US students, which makes our findings even more significant in terms of still engaging the majority of our subjects for long periods of 30-40 minutes each. Since this might be the case regardless of the domain and the population, once more, a facilitator can identify and provide the missing link between what is relevant to those students and the theme of the collaborative experience. Relevance—although not the focus of the current research—encompasses all the elements mentioned above and can lead to memorable museum visits by evoking powerful emotions through the exploration and discovery of personally meaningful experiences (Simon, 2016).

6.3 Design Guidelines

The cumulative findings from our studies informed a list of practical guidelines for the development of interactive learning games and virtual environments for the large groups of students visiting museums. The following list of guidelines aims to help museum educators, game developers, and related researchers to evaluate the cost-benefit ratio of applying game design for group engagement in public spaces of informal learning. The list is by no means exhaustive and even the suggested guidelines would need further validation before being applied for a specific domain and in a specific context. Our effort was mostly to improve learning practices by “making insights usable, actionable, and adoptable,” rather than to provide strong propositions (Bannan-Ritland, 2003).
Chapter VI – Conclusions

i. Facilitate the group’s learning experience with frequent interventions to maintain motivation to participate, sustain engagement, and resolve misconceptions.

Although we initially planned and envisioned a totally independent interactive experience for the group, we realized that facilitation is necessary for many reasons. Overall, it is really hard to account for the diverse audience visiting museums and similar spaces of informal learnings, hence a guide or facilitator can dynamically adapt the experience to the interests and expectations of the audience, making sure they stay engaged and get the most—in terms of learning—out of the experience.

ii. Provide equal opportunities for interaction between participants or alternate between more and less active roles.

Depending on group size, the game should be able to support either simultaneous interaction of participants (for small groups of 2-4 students), or the ability to switch roles on the fly giving the ability to students who are interested, to participate more actively (for larger groups).

iii. Increase agency in the game, when possible, and limit passive intervals.

Provide a high degree of control to participants, allowing them to directly affect the outcome of the game. Limit intervals when either the part of the group (i.e., less or more active participants) have no task to perform, which makes them feel detached from the game.

iv. Provide within-context information before troubleshooting instances to ensure equal levels of retention by all participants.

Since there is a different attention span for different groups and even individual students, provide brief, interesting snippets of information (or reminders if information was presented before) right when it is needed. Do not depend on long-term memory recall of information presented at the beginning of the experience or at a different context in the museum.

v. Encourage social interactions either through the game interface (intrinsic) or by motivating participants with extrinsic rewards, if necessary.

Social interactions afforded by the collocation of students needs to be facilitated for a rewarding experience with improved learning gains. Design activities that involve all students in troubleshooting problems and executing tasks as a group.
vi. Take into consideration the audience, including the culture and societal background, and also the setting of the informal learning experience.

The audience interaction paradigm we have created and tested in our work was mostly a proof-of-concept for evaluating the effectiveness of this approach. Other designs can and should be tested to best serve engaging content delivery for different audiences (e.g., younger vs older) and different settings (e.g., art or history museum).

6.4 Future Work

This dissertation research was just the first step in a direction we feel has not been adequately explored in the past and bears potential to best serve the most popular audience of museums around the world, young student groups. We see two main directions that this work can move to, considering our interest in maintaining the social aspect of the experience, which we think is one of the most important components of both learning and museum visits per se. Other directions are possible and have been considered during this work, such as comparing remote vs collocated multi-user virtual environments, but move beyond the main motivation of this research.

The first direction is focused on getting a deeper understanding about our existing research questions and gathering more solid evidence for some our tentative claims. We could, for example, design experiments where facilitation is a controlled variable, which we can vary in different interactive conditions. To augment such studies we could try different types of facilitation, such as guidance by an expert guide, human-guided interventions through the interface (in a “Wizard of Oz” style37), or anything in between. A deeper understanding about the level of involvement of the audience would also be a natural continuation of this work. We could design experiments with varying levels of involvement (instead of the two conditions used so far), where the audience could participate and intervene more or less frequently, using different mediums and devices. Especially considering the indications of higher involvement for longer information retention and increased learning for lower SES students, despite the lack of significant learning improvement between our two conditions overall, this is a highly suggested route for anyone continuing this research.

The second avenue is more about seeking solutions for problems identified in the existing game setup, which we believe affected collaborative attitudes and students’ social engagement.

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37 Wizard of Oz in HCI research refers to having subjects of an experiment believe they are interacting with an autonomous computer system, while the system is actually being operated or partially operated by an unseen human.
More specifically, we would like to explore alternative ways and technologies for facilitating a rich and engaging social interaction in these spaces. We have created and tested what we thought would serve the audience and the venue the most, i.e., an auditorium-style setup with a front-projected screen. However, a round arrangement with students interacting over a large table-top display might have been more effective. Also, we would like to test how physical movement in the space, incorporating ideas from embodied interaction design, could be harnessed in achieving a more enjoyable experience for the participants. How would these technologies and means of interaction affect the outcomes? What arrangement affords more social interactions? How do interactions over different devices and in different setups affect enjoyment and learning?

We also identified there were quite some differences in how students from different cultures and ethnic and socioeconomic backgrounds react and behave during a large-group collaborative experience. We would like to investigate ways in which these differences could be identified a priori, e.g., through a brief survey on the device, and content delivery could be adapted accordingly. Of course, in a game with a common interface this is extremely challenging, but the interface could be adaptable per participant on individual devices (such as the iPads in our work) and output presented on a common screen. The challenge then becomes how to combine information which is relevant to each individual (or groups of individuals) with the common goal of the game. Using our theme as an example, a student interested in cooking could be presented with information pertinent to the use of olive oil in global cuisine, while one with an interest in geography could be presented with information/trivia about the locations where olive oil is most popular in the world. Each participant could then contribute their piece of information in a game with a common goal, such as completing a board with details about olive oil production that the whole group could inspect and review at the end. Of course, not all students will get the exact same information but this is not the case with any museum visit anyway, where each visitor finds meaning and acquires the knowledge that is most relevant to his personal interests (Simon, 2016). Research, in this case, would focus more on the design and implementation of such multi-user interfaces that could identify user interests and monitor user progress, in order to provide a collectively enjoyable experience, where each student would acquire information that is most relevant to her and most probable to retain for a longer period of time.
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Ulicsak, M. (2010). *Games in Education: Serious Games*. Bristol, UK.


References


Appendix A: Experiment Documents

Collection of all the study material used during our three main experiments, including:

- VT IRB approval letters
- Recruiting letters (samples, if sent to multiple recipients)
- Informed consent and/or Parental Permission forms (if applicable)
- Knowledge quiz (copy from online/qualtrics or paper version)
- Questionnaires (copies from online/qualtrics or paper versions)
- Procedure instructions and scripts
- Interview script (if applicable)

(Note: Experiment number appears at the top left of the header on each odd page)
MEMORANDUM

DATE: June 28, 2013
TO: Doug A Bowman, Panagiotis Apostolellis
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE: C-OLIVE: Collaborative Orchestrated Learning in Virtual Environments
IRB NUMBER: 13-589

Effective June 27, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 6,7
Protocol Approval Date: June 27, 2013
Protocol Expiration Date: June 26, 2014
Continuing Review Due Date*: June 12, 2014

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal/ work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.
Recruitment Letters

Dear Sir/Madam,

We are delighted to be able to offer your child the opportunity to participate in a study about social game play in virtual reality environments. This is an innovative study in which we employ state of the art technology to engage three students at the same time with an educational game about olive oil production! We are interested in understanding the benefits of co-located collaborative play of middle-school children in informal learning settings, like science museums. Your child will have the unique opportunity to find out about the process of olive oil extraction and the machinery involved, either by watching a 3D movie {Auto} or playing a 3D game {1P or 3P} with peers on a projector screen.

This opportunity has been provided because of a partnership between the Imagination Summer Program and a Computer Science Lab on campus. Your child has been specially selected to participate and if you are interested there will be a short background survey and pre-participation quiz for your child to take before the experience.

Please reply to this email indicating if you would like to have your child participate in this unique educational video game study. If you would like to decline this offer we also ask that you indicate that through a reply so that we can extend the offer to another individual.

Sincerely,

David Henry
Imagination Director 2013
Dear Sir/Madam,

We are delighted to be able to offer your child the opportunity to participate in a study about social game play in virtual reality environments. This is an innovative study in which we employ state of the art technology to engage three students at the same time with an educational game about olive oil production. We are interested in understanding the benefits of co-located collaborative play of middle-school children in informal learning settings, like science museums. Your child will have the unique opportunity to find out about the process of olive oil extraction and the machinery involved, either by watching a 3D movie or playing a 3D game with peers on a projector screen.

This opportunity has been provided because of a partnership between the Roanoke Science Museum and the Center for Human Computer Interaction (CHCI) at Virginia Tech. Your child has been specially selected to participate and if you are interested you will need to complete and return the “parental permission form” attached on this letter. Then you will need to help you child connect to the web address at the end of this letter, to take a brief background survey and a quiz that will help in the analysis of the study. We kindly ask you to instruct your child to fill in the information to the best of his/her knowledge without any assistance either from you or any other source. Ideally, the online survey and quiz should be taken in one go and at least 10-15 days before the Camp.

Please reply to this email indicating if you would like to have your child participate in this unique educational video game study, by also attaching a signed copy of the parental permission form.

We would like to express our deepest appreciation for considering this opportunity. We hope that, if you agree to his/her participation, it will be as much of a rewarding experience for him/her as much it will be for us!

Sincerely,

Ann Shepherd, Roanoke Science Museum, Education Director
Panagiotis Apostolellis, PhD Candidate of Computer Science
Dr. Doug A. Bowman, Professor of Computer Science, CHCI Director

Demographic survey, and quiz link.
http://survey.qualtrics.com/SE/?SID=SV_0qP6hS7ze0iMCN
I. THE PURPOSE OF THIS RESEARCH/PROJECT

We are inviting your child to participate in a study where we evaluate social game play in virtual environments with the intent to understand if collaborative learning in informal education settings (e.g., science museums) can be more effective than individual play. This research constitutes a study of three different setups where groups of three children will learn about olive oil production in the Industrial Era, either by watching a digital movie, watching one child playing and negotiating information and plans of action, or playing all together an interactive game using Xbox controllers on a large projected display.

II. PROCEDURES

Initially, participants will receive this parental permission form through e-mail at least two weeks before the experiment, along with a link to a pre-test quiz with questions about olive oil production to act as a measurement of their prior knowledge on the subject matter. Demographic information and their experience with computer games and virtual reality applications will also be requested at the beginning of this online questionnaire. Upon arrival at the study venue, subjects will be given an introduction to our experiment background, goals, and facilities to be used, and study procedures; this will be achieved by reading a child-appropriate narrative to them. Next, they will watch a 2-minute movie introducing the basic concepts and procedures involved in olive oil production. Following the movie they will be randomly assigned to one of the study conditions and will have to do the following:

A) If participating in the interactive condition, they will be introduced to the application (“C-OLiVE: Collaborative Orchestrated Learning in Virtual Environments”) and the interaction device involved (a wireless Xbox controller), if they are chosen to have control of the application. They will be given a short period of time to get used to the game controller and familiarize themselves with tasks similar to the ones they will have to perform in the actual study environment, and all the interface elements employed in the game. After feeling comfortable with the interface they will start the main session of the experiment. Their task will involve starting steam production in an olive oil factory and producing a specific amount of olive oil by virtually operating accurate replicas of the involved machinery (e.g., mills, presses, pumps, etc.) in a representation of a real-world factory. The system will record a variety of information about their actions, like interaction with machinery, path followed through the factory, machine states, score, completion time, etc.

B) If participating in the non-interactive condition they will watch a pre-recorded movie with all the actions happening automatically, providing the exact same information, excluding feedback for erroneous choices. After this session, in all conditions, they will fill out a post-test questionnaire including the same questions as the pre-test, and also rate their experience with the system as far as engagement and feeling of presence is concerned. A free form interview will be conducted with any subjects who have any additional comments not addressed by the questionnaire. The main study session will be video-recorded in all three conditions using a digital camera filming the screen from the back of the room. A link for a follow-up study questionnaire for assessing long-term learning will be sent to some of the participants through e-mail.

III. RISKS

There will not be more than minimal risks involved in our study.

IV. BENEFITS OF THIS PROJECT

By providing permission for your child to participate in this study you will help us gather valuable information about prospective benefits of digital technology, more specifically virtual reality environments, for collaborative game-based learning in informal education settings. No guarantee of benefits has been made to encourage your child to participate. You may receive a synopsis summarizing this research when completed, upon request.
Appendix A: Experiment Documents

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

In the process of the research, your child will be photographed, audio-taped, and videotaped. The images and tapes will be used for teaching and research purposes (professional meetings and scholarly publications). Your child’s name will not be disclosed and the investigators will protect and/or disguise your child’s name when using photographs, videos, or audio-tape recordings, however, their face might be visible. All data, including images and recordings, will be maintained indefinitely on the investigators’ password-protected computers and/or in a locked office of one of the investigators. You have the right to review the tapes and photographs made as a part of the study to determine whether they should be edited or erased in whole or in part. The investigators and research assistants will transcribe, score, and analyze images and recordings. Any data gathered from your child will be identified by a numbered code only, preserving anonymity and confidentiality. Only pseudonyms will be associated with reported results, protecting confidentiality.

It is possible that the Virginia Tech Institutional Review Board (IRB) may view this study’s collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. COMPENSATION

Participation in this study is voluntary and unpaid.

VII. FREEDOM TO WITHDRAW

You may withdraw your child from the research project at any time and for any reason. Your child is free to not answer any questions without penalty. If activities are being videotaped, your child also has the right to ask that we stop the video recording at any time. To withdraw, please inform the camp staff or one of the persons listed at the bottom of this form.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science. Virginia Tech IRB Approval number: 13-589.

IX. PARENT OR GUARDIAN’S PERMISSION

I voluntarily agree to permit my child to participate in this study, and I know of no reason s/he cannot participate. I have read and understand the parental permission and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary permission for his/her participation in this project. If s/he participates, s/he may withdraw at any time without penalty. I agree to abide by the rules of this project.

_________________________                                         ______________________
Signature                                                                 Date

_________________________                          ______________________
Child’s name (please print)                                   Contact: e-mail (for follow-up study)

Contact: phone or address (optional)
Should I have any questions about this research or its conduct, I may contact:

**Investigators:**
Dr. Doug A. Bowman     Phone (540) 231-2058  
Professor, Computer Science Department  
email: dbowman@vt.edu

Panagiotis Apostolellis  
Graduate Student, Computer Science Department  
email: panaga@vt.edu

**Review Board:**
Dr. David Moore     Phone (540) 231-4991  
Chair, Virginia Tech Institutional Review Board  
For the Protection of Human Subjects  
Email: moored@vt.edu

cc: the participant, Dr. Doug A. Bowman, Panagiotis Apostolellis.
Appendix A: Experiment Documents

Pre-test Quiz | C-OLiVE

Q1 This is a brief quiz about industrialized olive oil production during the 1960s. Your answers will help us understand your knowledge level on the topic before you join us and experience the virtual olive oil factory game.

Q2 Please, type the exact same code name that you chose to use in the game:

Q3 Please respond to the following questions to the best of your knowledge. If you do not know the answer to any of the questions, select the “I don’t know” option instead of guessing.

Q4 How did the olive oil factory provide power to the machines involved in production?
   - Using petroleum
   - Using steam
   - Using manpower
   - Using horse power
   - I don’t know

Q5 What was the fuel that was used to heat the water inside the boiler?
   - Coal
   - Copper
   - Firewood
   - Olive pomace
   - I don’t know

Q6 How was the power transmitted from the engine to the rest of the factory?
   - Through electricity
   - Through belts and pulleys
   - Through water pipes
   - Through steel wires
   - I don’t know
Q7 Why was it necessary to have two workers in order to fill the mills with olives?

○ Because the olive sacks were located far away from the mills
○ Because the olive sacks were too heavy
○ Because the mills were too high
○ Because one worker had to hold the mill’s lid open
○ I don’t know

Q8 What was the minimum pressure in the boiler before machines started malfunctioning?

○ 80 psi
○ 100 psi
○ 120 psi
○ 200 psi
○ I don’t know

Q9 How was olive oil quality affected during the grinding process in the mills?

○ Prolonged grinding without watering down increased heat of the olive pulp
○ The pulp contained other substances which were transferred to the oil
○ Too many olives were loaded in the mills
○ The mill’s wheels were turning at a lower speed than appropriate
○ I don’t know

Q10 How many straw mats with olive pulp should each press have had before pressing would start?

○ At least 40
○ No more than 40
○ Until it was fully-loaded
○ Until it was half-loaded
○ I don’t know

Q11 What did the workers have to do to release a press after the process was finished?

○ Release the lever that gave power to the press
○ Wait until the press would release itself automatically
○ Move the belt of the corresponding pump back to the idle pulley
○ Close the hydraulic bypass valve of the corresponding pump
○ I don’t know
Appendix A: Experiment Documents

Q12 How was the unfiltered oil transferred from the presses to the oil separators?

- Using an oil pump and a system of pipes and oil gathering tanks
- Using a small cart where the press tanks were loaded
- Manually, using buckets which were emptied in bigger tanks
- There was no need because the separators were next to the presses
- I don’t know

Q13 How did the DeLaval separators separate the pure olive oil from the water?

- Using centrifuge power at high revolutions per minute (rpm)
- Using a system of pipes and vessels
- Using specialized chemical substances
- Using inertia where liquids were separated due to density difference
- I don’t know

Q14 Why might someone use a small cart in the olive press factory?

- To load the fuel inside the boiler furnace
- To load the olives from the sacks inside the mills
- To transfer the unfiltered olive oil near the separators
- To transfer the olive pulp from the mills to the press loading table
- I don’t know

Q15 In a good year, how many pounds of olives would produce 160lbs of pure olive oil?

- Less than 500 lbs
- Around 550 lbs
- Around 650 lbs
- More than 700 lbs
- I don’t know

Q16 Which two machines must be working at all times in order for the factory to operate?

- Boiler and press
- Engine and mill
- Engine and press
- Boiler and engine
- I don’t know
Q17 Where did the water coming out of the DeLaval separators come from?

- The water was used by the separator to prevent overheating
- The water is part of the olives themselves
- It was the water added during the grinding process
- It came both from the olives and the amount added during grinding
- I don’t know

Q18 What might have caused the press tray to break?

- Uneven load of the press tray with mats
- Increased pressure from the pump to the press
- Either or both of the above at the same time
- None of the above; the press tray was unbreakable
- I don’t know

Q19 What happened with the remains of the pulp in the mats after the pressing process?

- They were disposed
- They were used as fuel in the boiler
- They were consumed by the workers
- They were pressed again to produce more oil
- I don’t know

Q20 Which of the olive oil factory workers had to start work earlier in the day?

- The ones in charge of loading the mills with olives
- The ones who were maintaining the engine
- The ones in charge of starting up the boiler
- The ones who were loading the presses
- I don’t know
Q21 How many workers were needed in order to...

<table>
<thead>
<tr>
<th>Task</th>
<th>One</th>
<th>Two</th>
<th>I don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load and ignite the boiler</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Load the mills with olives</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Transfer the olive pulp from the mills to the loading table</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Load the mats with the olive pulp</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Load the presses with mats</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Operate the pump</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Attach belts to machines</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Load the unfiltered oil in the separators</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Transfer the oil containers to the scale</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Maintain a constant steam pressure to the engine</td>
<td>☑️</td>
<td>☑️</td>
<td>☑️</td>
</tr>
</tbody>
</table>

Q22 For the following two questions, please provide as accurate a response as possible according to your current knowledge.

Q23 Describe the process involved in getting the unfiltered olive oil from the olive pulp giving as many details as possible about machines and workers involved (if you don’t know leave it blank):

Q24 Describe the necessary tasks and machine operations that workers had to do in order to provide power to the olive oil production factory machinery (if you don’t know leave it blank):
Background Survey | C-OLiVE

Q1 Thank you very much for taking part in the olive oil factory game! First of all you have to choose a code name which you are going to use during the game, but also for every form you complete (like this one). Make sure you write this code name somewhere and bring it with you when you join us!

Q2 Type your chosen code name below (maximum 15 letters):

Q32 Great! Now, please help us learn some important things about you by completing the following items.

Q3 What is your gender?
☐ Boy
☐ Girl

Q4 How old are you?
☐ 11
☐ 12
☐ 13
☐ 14
☐ Other ____________________

Q5 What is your school grade?
☐ 6th
☐ 7th
☐ 8th
☐ Other ____________________
Appendix A: Experiment Documents

Q6 Do you wear glasses or contact lenses?
- No
- Glasses
- Contact lenses

Q7 You are:
- Left-handed
- Right-handed
- Ambidextrous (both hands)

Q8 How many hours a day do you use computers?
- None
- 0-1
- 1-3
- 3-6
- 6 or more

Q9 Do you play computer games?
- No
- Yes

Q10 On average, how many hours a day do you play computer games?
- None
- 0-1
- 1-2
- 2-3
- 3 or more

Q11 Have you used an Xbox, Playstation or similar controller when playing video games?
- No
- Yes

Q12 If yes, which controller(s) have you used?
Q13 How do you feel about computers and video games, in general?
⊙ I don't like them
⊙ I don't care
⊙ I like them a lot

Q14 Have you ever played any computer games with a 3-dimensional world?
⊙ No
⊙ Yes

Q15 If yes, which game(s)?

Q16 Have you ever experienced a virtual reality (VR) system that made you feel like you were inside the virtual world being displayed? (e.g., planetarium, theme park ride, etc.)?
⊙ No
⊙ Yes

Q17 If yes, describe the type(s) of technology the VR system used (e.g., large displays, head-mounted displays, 3D glasses, 3DTVs, etc.)

Q18 Have you ever played a game on a screen larger than your home TV?
⊙ No
⊙ Yes

Q19 If yes, what kind of display was that (e.g., wall projector)?

Q20 Have you played any multiplayer online game with other people (like Facebook games, World of Warcraft, Second Life, etc.)?
⊙ No
⊙ Yes
Appendix A: Experiment Documents

Q21 If yes, which game(s)?

Q22 Have you played a computer game together with friends where you had to collaborate in order to succeed in the game?
   - No
   - Yes

Q23 If yes, which game(s)?

Q24 How do you feel about playing computer games with friends and family?
   - I prefer playing alone
   - I don't care
   - I prefer playing with others
   - I don't like games!

Q25 If you like multi-player games, do you like to play online or together with friends at the same place?
   - I prefer playing online
   - I don't care
   - I like to play together
   - I don't like these games!

Q26 Do you know anything about olive oil and how it is produced?
   - No
   - Yes

Q27 If yes, what do you know?

Q28 Do you know how machines like stone mills, boilers, engines, and pumps work?
   - No
   - Yes

Q29 If yes, what do you know?
Experience Questionnaire | C-OLiVE

Q1 This brief questionnaire will allow you to express how the game make you feel. Think back to the experience and respond as truthfully as possible.

Q2 Please, type the exact same code name that you chose to use in the game:

Q3 Please, complete the following sentences by choosing the number that best describes your experience.

Q4 Please rate your sense of being in the olive oil factory. I had a sense of actually “being there” inside the olive oil factory...

☐ Not at all 1
☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ Very much 7

Q5 To what extent were there times during the experience when the olive oil factory and what was happening in it were the reality for you? There were times during the experience when the olive oil factory seemed like the reality for me...

☐ Rarely 1
☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ Very often 7
Appendix A: Experiment Documents

Q6 When you think back to the experience, do you think of the olive oil factory more as images that you saw or more as somewhere that you visited? The olive oil factory seems to me more like...

- Images I saw 1
- 2
- 3
- 4
- 5
- 6
- A place I visited 7

Q7 During the time of the experience, which was the strongest on the whole, your sense of being in the olive oil factory or of being elsewhere? I had a stronger sense of being...

- Elsewhere 1
- 2
- 3
- 4
- 5
- 6
- In the factory 7

Q8 During the time of your experience, did you often think to yourself that you were actually in the olive oil factory? During the experience I often thought that I was standing in the olive oil factory...

- Not at all 1
- 2
- 3
- 4
- 5
- 6
- Very much so 7

Q9 Select if you played the game with peers or if you watched a video of someone playing:

- I played with friends
- I watched a video of someone playing

Only if “I played with friends” is selected then the following question appears

Q10 For each of the following, please indicate how you felt while playing the game.
<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Slightly</th>
<th>Moderately</th>
<th>Fairly</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was interested in the game's story</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt confident while playing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt bored</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found the game impressive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>While playing, I forgot everything around me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing the game did not go as I wanted to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found it tiresome</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt good while playing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I had to put a lot of effort into the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The game made me nervous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I paid a lot of attention to the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt challenged by the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was good at it</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought it was fun to play the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoyed a lot playing with others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It was easy for me to work with my peers</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>I felt connected to the others</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>I paid close attention to the others</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>I felt jealous about the others</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>My actions depended on the others' actions</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The others' actions were dependent on my actions</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>What the others did affected what I did</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>What I did affected what the others did</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>I was ashamed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>I was shy</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Child-Appropriate Narrative Explaining the Study – **Auto Condition**

<table>
<thead>
<tr>
<th>Begin</th>
<th>-</th>
<th>We assume that all three students are already at the designated testing area and have a permission form signed by their parents/guardians.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>1’</td>
<td>Thank you for coming to see us! We are testing a three-dimensional computer game about industrialized olive oil production. Isn’t that an exciting subject? We would like you to watch someone else playing with the game and then take a quiz to see how much you’ve learned about olive oil production. Most importantly, we need you to tell us how the game made you feel; your opinion and advice are a significant part of the study!</td>
</tr>
<tr>
<td><strong>Code name</strong></td>
<td>1’</td>
<td>We will keep your identity secret, this why you provided a code name when filling the online survey. All of your results will be saved under this code name and the only connection between your code name and real name will be kept on a file which we will store in a secure computer drive, separate from the rest of the information.</td>
</tr>
<tr>
<td><strong>Walkthrough</strong></td>
<td>1’</td>
<td>I will briefly walk you through the process of this study and would like you to let me know if you have any questions, at any point. &lt;read process briefly&gt;</td>
</tr>
<tr>
<td><strong>Withdraw</strong></td>
<td>-</td>
<td>The whole process takes approximately an hour to complete and it will be video recorded. You can stop at any time! You can also take a break, or you can withdraw from the study at any time, for any reason or no reason at all.</td>
</tr>
<tr>
<td><strong>Assent</strong></td>
<td>1’</td>
<td>Do you all agree to participate in the study? &lt;get verbal assent and store their real-code name combination in a password-protected Excel file&gt;</td>
</tr>
<tr>
<td><strong>Condition</strong></td>
<td>1’</td>
<td>You will first watch a brief introductory video and then watch someone play the game. Remember that the purpose of the game is to operate the factory and produce olive oil.</td>
</tr>
<tr>
<td><strong>Video</strong></td>
<td>5’</td>
<td>You will now watch a 5-min video describing the operation of an olive oil factory with all the main processes explained. Please, try to pay as much attention as possible to the information provided, because it will help you understand how the factory works and what the workers had to do to operate the machinery. &lt;Play the video&gt;</td>
</tr>
<tr>
<td><strong>Practice</strong></td>
<td>5’</td>
<td>Before we start the game, I want to make sure that you understand the game interface. This is why I will give you a brief demonstration inside the factory but without the actual machinery. However, everything else is exactly the same. &lt;Start practice and demonstrate interface&gt;</td>
</tr>
<tr>
<td><strong>Main trial</strong></td>
<td>15’</td>
<td>Now is the fun part! You will get to see someone else working inside the factory and perform all the necessary operations in order to produce olive oil; when two containers of olive oil have been produced the game is finished. Your goal is to attend to all the actions that the player is doing, as well as the information messages and alert messages that pop-up. You are free and to talk and discuss about what’s happening, which might help you better to understand</td>
</tr>
<tr>
<td>Activity</td>
<td>Duration</td>
<td>Instructions</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Post-exper. survey</td>
<td>5’</td>
<td>I would like each one of you to take this brief survey about how the game made you feel. Please, write your responses by being as truthful as possible. Remember that these responses are used to evaluate the game, not you, so please be relaxed. <em>Hand them the presence and experience questionnaire and make sure they select “I watched someone else play.”</em></td>
</tr>
<tr>
<td>Quiz</td>
<td>10’</td>
<td>The last thing I need you to do is take the quiz with general questions about the information you saw in the video and the game. Try to remember and think as much as possible about the actions that the player performed in the factory before answering the questions. If you don’t know an answer, please select “I don’t know” instead of guessing. <em>Hand them the quiz.</em></td>
</tr>
<tr>
<td>Thank you</td>
<td></td>
<td>Thank you for participating in our experiment.</td>
</tr>
</tbody>
</table>
# Child-Appropriate Narrative Explaining the Study – 1P Condition

<table>
<thead>
<tr>
<th>Begin</th>
<th>-</th>
<th>We assume that all three students are already at the designated testing area and have a permission form signed by their parents/guardians.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1’</td>
<td>Thank you for coming to see us! We are testing a three-dimensional computer game about industrialized olive oil production. Isn’t that an exciting subject? We would like you to play with the game and then take a quiz to see how much you’ve learned about olive oil production. Most importantly, we need you to tell us how the game made you feel; your opinion and advice are a significant part of the study! Please remember that the purpose of this study is not to assess your performance or test how well you did, so we ask you to play like you would play any kind of game.</td>
</tr>
<tr>
<td>Code name</td>
<td>1’</td>
<td>We will keep your identity secret, this why you will use in the game the code name you provided when filling the online survey. All of your results will be saved under this code name and the only connection between your code name and real name will be kept on a file which we will store in a secure computer drive, separate from the rest of the information.</td>
</tr>
<tr>
<td>Walkthrough</td>
<td>1’</td>
<td>I will briefly walk you through the process of this study and would like you to let me know if you have any questions, at any point. &lt;read process briefly&gt;</td>
</tr>
<tr>
<td>Withdraw</td>
<td>-</td>
<td>The whole process takes approximately an hour and a half to complete and it will be video recorded. You can stop at any time! You can also take a break, or you can withdraw from the study at any time, for any reason or no reason at all.</td>
</tr>
<tr>
<td>Assent</td>
<td>1’</td>
<td>Do you all agree to participate in the study? &lt;get verbal assent and store their real-code name combination in a password-protected Excel file&gt;</td>
</tr>
<tr>
<td>Condition</td>
<td>1’</td>
<td>You will first watch a brief video and then have to work together to operate the olive oil factory yourselves. One of you will have the control of the game at all times and the rest of you should help him/her do the necessary actions as much as you can. Remember that the purpose of the game is to operate the factory and produce olive oil. The control of the game will be given to the one whose code name is closer to A (or Z) &lt;decide their role according to the rule&gt;</td>
</tr>
<tr>
<td>Video</td>
<td>5’</td>
<td>You will now watch a 5-min video describing the operation of an olive oil factory with all the main processes explained. Please, try to pay as much attention as possible to the information provided, because it will help you understand how the factory works and make your life easier while playing the game. &lt;play the video&gt;</td>
</tr>
<tr>
<td>Practice</td>
<td>10’</td>
<td>Before we start the game, I want to make sure that the person playing the game knows how to operate the game controller and is ready to work in the factory and that all of you understand the game interface. This is why you will have 10mins to play inside the factory but without the actual machinery. However, everything else including the interface and controls are exactly the same. You</td>
</tr>
</tbody>
</table>
### Appendix A: Experiment Documents

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
</table>
| Main trial             | 30'-45'  | You will get to work all together to help the person controlling the game perform all the necessary operations in order to produce olive oil; when two containers of olive oil have been produced the game is finished. Your goal is to attend to all the information messages and alert messages that pop-up and troubleshoot problems as promptly as possible. This will not only increase your score but also allow you to finish the game faster. Try to complete the tasks and solve the problems on your own remembering what you saw in the video. If you get really stuck then I will be here to assist you. **It is really important that you all try to work together as closely as possible at all times and communicate about what you are doing.** Do you have questions at this point? **Respond to any questions**
|                        |          | Are you ready to play? **Start main trial and enter player code name**                                                                  |
| Post-exper. survey     | 5’       | I would like each one of you to take this brief survey about how the game made you feel. Please, write your responses by being as truthful as possible. Remember that these responses are used to evaluate the game, not you, so please be relaxed **Hand them the presence and experience questionnaire** |
| Quiz                   | 10’      | The last thing I need you to do is take the quiz with general questions about the information you saw in the video and the game. Try to remember and think as much as possible about the actions that you performed as a team in the factory before answering the questions. If you don’t know an answer, please select “I don’t know” instead of guessing. **Hand them the quiz** |
| Thank you              | -        | Thank you for participating in our experiment.                                                                                           |
Child-Adequate Narrative Explaining the Study – **3P Condition**

<table>
<thead>
<tr>
<th>Begin</th>
<th>-</th>
<th><em>We assume that all three students are already at the designated testing area and have a permission form signed by their parents/guardians.</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>1’</td>
<td>Thank you for coming to see us! We are testing a three-dimensional computer game about industrialized olive oil production. Isn’t that an exciting subject? We would like you to play with the game and then take a quiz to see how much you’ve learned about olive oil production. Most importantly, we need you to tell us how the game made you feel; your opinion and advice are a significant part of the study! Please remember that the purpose of this study is not to assess your performance or test how well you did, so we ask you to play like you would play any kind of game.</td>
</tr>
<tr>
<td><strong>Code name</strong></td>
<td>1’</td>
<td>We will keep your identity secret, this why you will use in the game the code name you provided when filling the online survey. All of your results will be saved under this code name and the only connection between your code name and real name will be kept on separate file which we will store in a secure computer drive, separate from the rest of the information.</td>
</tr>
<tr>
<td><strong>Walkthrough</strong></td>
<td>1’</td>
<td>I will briefly walk you through the process of this study and would like you to let me know if you have any questions, at any point. <em>&lt;read process briefly&gt;</em></td>
</tr>
<tr>
<td><strong>Withdraw</strong></td>
<td>-</td>
<td>The whole process takes approximately an hour and a half to complete and it will be video recorded. You can stop at any time! You can also take a break, or you can withdraw from the study at any time, for any reason or no reason at all.</td>
</tr>
<tr>
<td><strong>Assent</strong></td>
<td>1’</td>
<td>Do you all agree to participate in the study? <em>&lt;get verbal assent and store their real-code name combination in a password-protected Excel file&gt;</em></td>
</tr>
<tr>
<td><strong>Condition</strong></td>
<td>1’</td>
<td>You will first watch a brief video and then have to work together to operate the olive oil factory yourselves. All of you will get to control the game and have to work together to perform the necessary actions. Remember that the purpose of the game is to operate the factory and produce olive oil.</td>
</tr>
<tr>
<td><strong>Video</strong></td>
<td>5’</td>
<td>You will now watch a 5-min video describing the operation of an olive oil factory with all the main processes explained. Please, try to pay as much attention as possible to the information provided, because it will help you understand how the factory works and make your life easier while playing the game. <em>&lt;play the video&gt;</em></td>
</tr>
<tr>
<td><strong>Practice</strong></td>
<td>10’</td>
<td>Before we start the game, I want to make sure that everyone knows how to operate the game controller and is ready to work in the factory. This is why you will have 10 mins to play inside the factory but without the actual machinery. However, everything else including the interface and controls are exactly the same. You are going to use this Xbox controller <em>&lt;hand in controllers and start practice&gt;</em>. I want you to follow these instructions <em>&lt;read practice script&gt;</em>.</td>
</tr>
<tr>
<td>Activity</td>
<td>Duration</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Main trial</td>
<td>30'-45'</td>
<td>Now is the fun part! You will get to work all together and collaborate whenever necessary to perform all the necessary operations in order to produce olive oil; when two containers of olive oil have been produced the game is finished. Your goal is to attend to all the information messages and alert messages that pop-up and troubleshoot problems as promptly as possible. This will not only increase your score but also allow you to finish the game faster. Try to complete the tasks and solve the problems on your own remembering what you saw in the video. If you get really stuck then I will be here to assist you. <strong>It is really important that you all try to work together as closely as possible at all times and communicate about what you are doing.</strong> Do you have questions at this point? &lt;Respond to any questions&gt; Are you ready to play? &lt;Start main trial and enter players code names&gt;</td>
</tr>
<tr>
<td>Post-exper. survey</td>
<td>5’</td>
<td>I would like each one of you to take this brief survey about how the game made you feel. Please, write your responses by being as truthful as possible. Remember that these responses are used to evaluate the game, not you, so please be relaxed &lt;Hand them the presence and experience questionnaire&gt;</td>
</tr>
<tr>
<td>Quiz</td>
<td>10’</td>
<td>The last thing I need you to do is take the quiz with general questions about the information you saw in the video and the game. Try to remember and think as much as possible about the actions that you or your peers performed in the factory before answering the questions. If you don’t know an answer, please select “I don’t know” instead of guessing. &lt;Hand them the quiz&gt;</td>
</tr>
<tr>
<td>Thank you</td>
<td>-</td>
<td>Thank you for participating in our experiment.</td>
</tr>
</tbody>
</table>
# Practice session instructions

Start practice session and give the following instructions.

<table>
<thead>
<tr>
<th>No</th>
<th>Instruction</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[3P] Indicate which player plays in which window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Navigation</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Explain navigation controls and let them try them</td>
<td>2’</td>
</tr>
<tr>
<td>3</td>
<td>Show the map and let them navigate between the rooms</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Indicate that navigation is easier when looking through their window</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Explain the alerts and alert messages and have them approach an alert point</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Indicate that map should be used to spot where alerts and other players are</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>[3P] Emphasize they need to use the map to indicate their position to others</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Show where the tools storage is and ask them to go there</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interaction</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Explain interaction controls and have them pick, select, drop tools (red color)</td>
<td>3’</td>
</tr>
<tr>
<td>10</td>
<td>Explain the use of the D-pad and alternative ways of using/picking objects</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Have them approach the pipe and find out what the problem is</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Ask them to interact with the pipe’s components and show green color</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Show them the feedback on their action provided in the side panel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collaboration</td>
<td>5’</td>
</tr>
<tr>
<td>14</td>
<td>[3P] Emphasize that it is important to talk to each other to find a solution</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>[3P] Have two of them select a component and explain orange color</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>[3P] Have two of them troubleshoot the pipe problem</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>[3P] Have the third troubleshoot the other problem</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>[3P] Explain they have to click at the same time to perform team activity</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>[1P] Show the “Team work needed” icon and explain how it works</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>When the problem is solved show them the factory status update (‘info’)</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Indicate the points earned for every action they perform</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Explain that they have to attend to all messages to know what is happening</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Tell them about the warning sound when new alert/warning appears</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recap</td>
<td>2’</td>
</tr>
<tr>
<td>24</td>
<td>Indicate that the alerts/problem re-appear for practice purposes</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>[3P] Ask if they want to try again with different couples</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Experiment Documents

Exit Interview

Group #______       Date: __________

1. Which one was more helpful in responding to the quiz questions, the video or the game? Why?

1P, 3P

2. What did you like/dislike the most about the game?

3. What was one thing that was especially frustrating that really bothered you?

4. Was there any one thing that made this fun?

5. Did you use the map? Did you like it? Was it easy to attend to your window and the map?

6. How was the teamwork? Could you work easily together?

1P (non-controllers)

7. How was it just watching someone else control?

1P (controller)

8. How was it having them talk to you while you were controlling?
MEMORANDUM
DATE: March 13, 2014
TO: Doug A Bowman, Panagiotis Apostolopoulos
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE: C-OLIVE experiment II: group learning in museums
IRB NUMBER: 14-305

Effective March 13, 2014, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:
Approved As: Exempt, under 45 CFR 46.110 category(ies) 2
Protocol Approval Date: March 13, 2014
Protocol Expiration Date: N/A
Continuing Review Due Date*: N/A

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:
Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.
Dear Sir/Madam,

my name is Panagiotis Apostolellis and I am a PhD student of Computer Science at Virginia Polytechnic Institute and State University (Virginia Tech), in the US. The reason of writing to you is to inform you about my plans concerning a research study I wish to conduct at the Nikos Kazantzakis Museum (NKM) in Heraklion, with students of the 5th and 6th grade of elementary school and the three grades of middle school. I include some detailed information in order for you to better understand my research objectives.

My research aims in better understanding the benefits of collaborative learning with computer applications in museums. I have already implemented the first part in the US, in different schools and informal learning spaces (mainly summer programs). In cooperation with the NKM and the assistance of Antonis Levendis on its behalf, I wish to conduct the second part of my research in order to respond to the following questions:

- What is the impact of prior learning in informal education spaces?
- How is learning affected from the experimental setting (controlled or ecological)?
- The impact of different levels of interaction and the contribution of a facilitator (i.e., a museum educator facilitating the learning experience).

In order to respond to the above questions, I will employ groups of three students who will participate in the following three experimental conditions, using a 3D virtual reality (VR) representation of a steam-powered olive oil production factory:

**M)** The museum educator controls the game and asks/guides the children (existing, common way of displaying digital exhibits to groups in museums)

**1P)** One student is playing and the other two are assisting and contributing to the gameplay

**3P)** All three students are playing together

Students participate in the last two conditions using wireless Xbox controllers and need to collaborate in order to operate the machinery (i.e., boiler, steam engine, mills, presses, pumps, and separators), in order to produce olive oil. The application is based on the real process that was followed until the mid-19th century at the community olive oil factory of a village on the island of Lesvos, Greece, and has been implemented with the help of the Cultural Institute of Pireaus Bank Foundation that manages the Museum of Industrialized Olive Oil Production on the island. I include below some images from the virtual olive oil factory to provide a clearer image of the application content.
The procedure of the experiment is the following:

- Notification of the parents, prior to the experiment, of the research being approved by the Institutional Review Board of Virginia Tech (pending approval)
- Welcome students and explain the study procedure
- Pre-test about the subject domain (may be distributed in class)
- Practice with the application and the game controllers
- Game play (interaction with the virtual factory; see http://youtu.be/mPuNwW2zzW0)
- Game experience questionnaire
- Post-test (the same as the pre-test)

The game, based on our prior experience, lasts for thirty minutes to one hour (depending on the game controlling experience and the level of knowledge on the subject matter), and an extra half an hour for the remaining procedure of survey taking (depending on the speed of thinking/typing of the students). All the surveys are online and will be completed using iPads or workstations installed in the museum. Students will enter the study space in groups of three, where the aforementioned procedure will be followed.

What is demanded from your school is the allocation of one or more classrooms of the desired group age (11 to 15 years old) for an educational field trip to the museum, in order for me to use them for my experiment. The maximum number of students I can use for the 3.5 hours of the museum visit (9:30am – 1:00pm) is eighteen (18), using two study setups with three students per setup with an average duration of one hour and ten minutes. I would like to kindly ask you to contribute to my endeavor in recruiting as many students as possible, in order for me to start the conversion of the application in Greek, but also proceed with the approval demanded from my University. Since May is the optimal time for all parties involved, I would appreciate if I can have a definite response for the reasons above, but also to make the necessary travel arrangements.

For any questions or clarification about the educational program and its operation, please do not hesitate to contact me or Mr. Levendis at 6972333251.

Best Regards,
Panagiotis Apostolellis
{contact details}

Best Regards,
Dr Doug A. Bowman
{contact details}
ΕΙΣΑΓΩΓΙΚΟ ΚΟΥΙΖ   {Introductory Quiz}

Q1 Αυτό είναι ένα σύντομο κουίζ σχετικά με τη βιομηχανική παραγωγή ελαιολάδου κατά τα μέσα του 1900. Οι απαντήσεις σου θα μας βοηθήσουν να κατανοήσουμε το επίπεδο γνώσεών σου σχετικά με το αντικείμενο, πριν παίξεις το παιχνίδι με το Εικονικό Ελαιοτριβείο.

Q2 Γράψε ξανά το κωδικό όνομα που επέλεξες:

Q3 Παρακαλώ, απάντησε στις κάτωθι ερωτήσεις όσο καλύτερα μπορείς. Αν δεν γνωρίζεις την απάντηση σε οποιαδήποτε από τις ερωτήσεις, επιλέξε «Δεν γνωρίζω» αντί να μαντέψεις.

Q4 Την εποχή αυτή, πως παρείχε κίνηση το εργοστάσιο στα μηχανήματα που χρησιμοποιούνταν για να παράγουν το λάδι;
   ☐ Με πετρελαίο
   ☐ Με ατμό
   ☐ Χειροκίνητα
   ☐ Με τη δύναμη των αλόγων
   ☐ Δεν γνωρίζω

Q5 Τι καύσιμο χρησιμοποιούσαν για να θερμάνουν το νερό μέσα στον λέβητα;
   ☐ Κάρβουνο
   ☐ Χαλκό
   ☐ Καυσόξυλα
   ☐ Ελαιοπυρήνα
   ☐ Δεν γνωρίζω

Q6 Πως γινόταν η μετάδοση της κίνησης από τη μηχανή στο υπόλοιπο εργοστάσιο;
   ☐ Με ηλεκτρισμό
   ☐ Με μάντες και τροχαλίες
   ☐ Με σωλήνες νερού
   ☐ Με συμπλόσχοινα
   ☐ Δεν γνωρίζω
Q7 Γιατί χρειαζόταν δύο εργάτες για να γεμίσουν τους μύλους με τις ελιές;
☐ Επειδή τα σακία με τις ελιές ήταν αποθηκευμένα μακριά από τους μύλους
☐ Επειδή τα σακία με τις ελιές ήταν πολύ μεγάλα
☐ Γιατί οι μύλοι ήταν πολύ ψηλοί
☐ Γιατί ο ένας εργάτης έπρεπε να κρατάει το καπάκι του μύλου ανοικτό
☐ Δεν γνωρίζω

Q8 Ποια ήταν η ελάχιστη πίεση στον λέβητα πριν αρχίσουν οι μηχανές να υπολειτουργούν;
☐ 80 psi
☐ 100 psi
☐ 120 psi
☐ 200 psi
☐ Δεν γνωρίζω

Q9 Πώς επηρεάστηκαν η ποιότητα του λαδιού κατά τη διάρκεια της άλεσης μέσα στους μύλους;
☐ Παρατεταμένη άλεση χωρίς διάλυση με νερό αυξάνε τη θερμοκρασία του ελαιοπολτού
☐ Ο ελαιοπολτός περιείχε άλλες ουσίες που μεταφερόταν στο λάδι
☐ Υπερφόρτωση του μύλου με ελιές
☐ Οι τροχοί του μύλου γυρνούσαν με χαμηλότερη ταχύτητα από την απαιτούμενη
☐ Δεν γνωρίζω

Q10 Πόσα ελαιόπανα με ελαιοπολτό έπρεπε να έχει κάθε πρέσα πριν ξεκινήσει η πίεση;
☐ Τουλάχιστον 40
☐ Όχι πάνω από 40
☐ Μέχρι να ήταν πλήρως γεμάτη
☐ Μέχρι να ήταν μισογεμάτη
☐ Δεν γνωρίζω

Q11 Τι έπρεπε να κάνουν οι εργάτες για να απελευθερώσουν την πρέσα μετά το τέλος της διαδικασίας;
☐ Να απελευθερώσουν το μοχλό που έδινε ισχύ στην πρέσα
☐ Να περιμένουν μέχρι η πρέσα να απελευθερωθεί αυτόματα
☐ Να μεταφέρουν τον ιμάντα πίσω στην «τρελή» τροχαλία
☐ Να χειροκίνησαν τη βαλβίδα ανακούφισης της αντίστοιχης αντλίας
☐ Δεν γνωρίζω

Q12 Πως γινόταν η μεταφορά του ακαθάριστου λαδιού από τις αντλίες στους διαχωριστές;
☐ Χρησιμοποιώντας μία αντλία λαδιού και ένα σύστημα με σωλήνες και δεξαμενές
☐ Χρησιμοποιώντας ένα μικρό καρότσι όπου φόρτωναν τα πολύμια (μεταλλικά δοχεία)
☐ Χειροκίνητα, χρησιμοποιώντας κουβάδες που τους άδειαζαν σε μεγαλύτερες δεξαμενές
☐ Δεν ήταν απαραίτητο, γιατί οι διαχωριστές ήταν δίπλα στις πρέσες
☐ Δεν γνωρίζω
Appendix A: Experiment Documents

Q13 Πως διαχωρίζαν οι διαχωριστές Λαβάλ το καθαρό ελαιόλαδο από το νερό;
- Με φυγόκεντρο δύναμη σε υψηλές στροφές το λεπτό (στιλ)
- Με ένα σύστημα από σωλήνες και δοχεία
- Με εξειδικευμένες χημικές ουσίες
- Με αδράνεια όπου τα υγρά διαχωρίζονταν λόγω διαφοράς πίεσης
- Δεν γνωρίζω

Q14 Γιατί μπορεί κάποιος να χρησιμοποιούσε ένα καροτσάκι μέσα στο ελαιοτριβείο;
- Για να φορτώσει το καύσιμο μέσα στο φούρνο του λέβητα
- Για να φορτώσει τις ελιές από τα σακία μέσα στους μύλους
- Για να μεταφέρει το ακαθάριστο λάδι κοντά στους διαχωριστές
- Για να μεταφέρει τον ελαιοπολτό από τους μύλους στο τραπέζι φόρτωσης των πρεσών
- Δεν γνωρίζω

Q15 Σε μία καλή χρονιά, πόσα κιλά ελιές θα παρήγαγαν 80 κιλά καθαρού ελαιολάδου;
- Λιγότερο από 250 κιλά
- Περίπου 280 κιλά
- Περίπου 320 κιλά
- Περισσότερα από 350 κιλά
- Δεν γνωρίζω

Q16 Ποιά δύο μηχανήματα έπρεπε να δουλεύουν συνεχώς έτσι ώστε να λειτουργεί το εργοστάσιο;
- Η λέβητα και η πρέσα
- Η μηχανή κι ο μύλος
- Η μηχανή και η πρέσα
- Ο λέβητας και η μηχανή
- Δεν γνωρίζω

Q17 Από πού προερχόταν το νερό που έβγαινε από τους διαχωριστές Λαβάλ;
- Το νερό χρησιμοποιούνταν από τους διαχωριστές για την αποφυγή υπερθέρμανσης
- Το νερό είναι μέρος από τις ίδιες τις ελιές
- Ήταν το νερό που πρόσθεταν κατά τη διάρκεια της άλεσης
- Προερχόταν τόσο από τις ελιές όσο και από τη ποσότητα που πρόσθεταν κατά την άλεση
- Δεν γνωρίζω

Q18 Τι μπορούσε να προκαλέσει ζημιά στη λεκάνη της πρέσας;
- Άνιση φόρτωση της λεκάνης της πρέσας με ελαιόπανα
- Αυξημένη πίεση από την αντλία προς τη πρέσα
- Το ένα ή και τα δύο από τα παραπάνω ταυτόχρονα
- Κανένα από τα παραπάνω· η πρέσα ήταν άθραυστη
- Δεν γνωρίζω
Q19 Τι γινόταν τα υπολείμματα του ελαιοπολτού στα ελαιόπανα μετά τη διαδικασία πίεσης;
- Τα πετούσαν
- Τα χρησιμοποιούσαν ως καύσιμο στον λέβητα
- Τα κατανάλώναν οι εργάτες
- Τα πίεζαν ξανά για να παράγουν περισσότερο λάδι
- Δεν γνωρίζω

Q20 Ποιοι από τους εργάτες του εργοστασίου έπρεπε να ξεκινήσουν δουλειά νωρίτερα το πρωί;
- Εκείνοι που φόρτωναν τους μύλους με ελιές
- Εκείνοι που συντηρούσαν τη μηχανή
- Εκείνοι που άναβαν τον λέβητα
- Εκείνοι που φόρτωναν τις πρέσες
- Δεν γνωρίζω

Q21 Πόσοι εργάτες ήταν απαραίτητοι για να...

<table>
<thead>
<tr>
<th>Ένας</th>
<th>Δύο</th>
<th>Δεν γνωρίζω</th>
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<tbody>
<tr>
<td>Γεμίσουν και βάλουν σε λειτουργία τον λέβητα</td>
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<tr>
<td>Φορτώσουν τους μύλους με ελιές</td>
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<tr>
<td>Μεταφέρουν τον ελαιοπολτό από τους μύλους στο τραπέζι φόρτωσης των πρέσων</td>
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<tr>
<td>Γεμίσουν τα ελαιόπανα με ελαιοπολτό</td>
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<td>Φορτώσουν τα ελαιόπανα στις πρέσες</td>
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<tr>
<td>Λειτουργήσουν τις αντλίες</td>
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<tr>
<td>Συνδέσουν τους μήντες στις μηχανές</td>
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<tr>
<td>Φορτώσουν το ακαθάριστο λάδι στους διαχωριστές</td>
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<tr>
<td>Μεταφέρουν τα δοχεία λαδιού στη ζυγαρία</td>
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<tr>
<td>Διατηρήσουν μία σταθερή πίεση ατμού στο λέβητα</td>
<td>o</td>
<td>o</td>
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</table>
Q22 Για τις ακόλουθες δύο ερωτήσεις απάντησε όσο καλύτερα μπορείς σύμφωνα με τις τωρινές σου γνώσεις.

Q23 Περιέγραψε τη διαδικασία που απαιτείται για να πάρουμε το ακαθάριστο λάδι από τον ελαιοπολτό, δίνοντας όσο περισσότερες πληροφορίες μπορείς για τα μηχανήματα και τους εργάτες που εμπλέκονται (αν δεν γνωρίζεις αφήσε το κενό):

Q24 Περιέγραψε τις απαραίτητες εργασίες και λειτουργίες μηχανών που έπρεπε να κάνουν οι εργάτες για να παρέχουν ισχύ στα μηχανήματα ελαιοπαραγωγής του ελαιοτριβείου (αν δεν γνωρίζεις αφήσε το κενό):
ΓΕΝΙΚΕΣ ΠΛΗΡΟΦΟΡΙΕΣ {General Information}

Q1 Σ’ ευχαριστούμε πολύ για τη συμμετοχή σου στο παιχνίδι με το Εικονικό Ελαιοτριβείο. Συμπληρώνοντας αυτό το ερωτηματολόγιο συμφωνείς να συμμετάσχεις στην έρευνα για μάθηση με παιχνίδια σε μουσεία. Η βοήθειά σου είναι πολύ σημαντική για εμάς!

Κατ’ αρχήν πρέπει να διαλέξεις το κωδικό όνομα που πρόκειται να χρησιμοποιήσεις τόσο κατά τη διάρκεια του παιχνιδιού, όσο και σε κάθε φόρμα που συμπληρώνεις (όπως αυτή εδώ). Καλό θα είναι να βεβαιωθείς πως σημειώσεις κάπου αυτό το κωδικό όνομα ώστε να το θυμάσαι όταν θα παίξεις.

Q2 Γράψε παρακάτω το κωδικό όνομα που επέλεξες με αγγλικά γράμματα (έως 15 χαρακτήρες):

Q3 Τέλεια! Τώρα βοήθησε μας να μάθουμε κάποιες σημαντικές πληροφορίες για σένα, συμπληρώνοντας τις παρακάτω ερωτήσεις.

Q4 Είσαι:
  ○ Αγόρι
  ○ Κορίτσι

Q5 Πόσο χρονών είσαι:
  ○ 11
  ○ 12
  ○ 13
  ○ 14
  ○ 15
  ○ Άλλο __________________

Q6 Σε ποια τάξη πηγαίνεις:
  ○ Ε' Δημ.
  ○ ΣΤ' Δημ.
  ○ Α' Γυμν.
  ○ Β' Γυμν.
  ○ Γ' Γυμν.
  ○ Άλλη __________________
Appendix A: Experiment Documents

Q7 Πόσες ώρες τη μέρα χρησιμοποιείς υπολογιστές (PC, iPad, ταμπλέτες, κλπ.)
  ○ Καμία
  ○ 0-1
  ○ 1-3
  ○ 3-6
  ○ 6 ή περισσότερες

Q8 Παίζεις παιχνίδια σε υπολογιστές (PC, iPad, iPhone, ταμπλέτες, Wii, Kinect, κλπ.);
  ○ Όχι
  ○ Ναι

Q9 Κατά μέσο όρο, πόσες ώρες την ημέρα παίζεις παιχνίδια σε υπολογιστές;
  ○ Καμία
  ○ 0-1
  ○ 1-2
  ○ 2-3
  ○ 3 ή περισσότερες

Q10 Ποια από τα παρακάτω χειριστήρια έχεις χρησιμοποιήσει για να παίξεις παιχνίδια;
    ○ Xbox 360
    ○ Playstation
    ○ Wii
    ○ Sony Move
    ○ Κανένα

Q11 Πως νοιώθεις γενικά για τα παιχνίδια σε υπολογιστή;
  ○ Δεν μου αρέσουν
  ○ Δεν με νοιάζει
  ○ Μου αρέσουν πολύ

Q12 Έχεις παίξει ποτέ κάποιο παιχνίδι με τρισδιάστατα γραφικά (π.χ. Minecraft, Mario Kart, Call of Duty);
  ○ Όχι
  ○ Ναι

Q13 Έχεις ποτέ κάποια εμπειρία με σύστημα εικονικής πραγματικότητας, όπου ένοιωθες πως ήσουν μέσα σε έναν φανταστικό κόσμο (π.χ. πλανητάριο, τρισδιάστατα γυαλιά, 3DTV);
  ○ Όχι
  ○ Ναι
Q14 Έχεις παίξει ποτέ ένα παιχνίδι σε οθόνη μεγαλύτερη από την τηλεόραση του σπιτιού σου (π.χ. προβολέας τοίχου);
- Όχι
- Ναι

Q15 Έχεις παίξει ποτέ κάποιο παιχνίδι στο Internet με άλλα άτομα (π.χ. παιχνίδια στο Facebook, World of Warcraft, Second Life, κλπ.);
- Όχι
- Ναι

Q16 Έχεις παίξει με φίλους κάποια παιχνίδια που έπρεπε να συνεργαστείτε για να νικήσετε (π.χ. Mario, Minecraft, Call of Duty, κλπ.);
- Όχι
- Ναι

Q17 Πως αισθάνεσαι όταν παίζεις παιχνίδια σε υπολογιστή με την οικογένεια ή τους φίλους σου;
- Προτιμώ να παίζω μόνος μου
- Δεν με νοιάζει
- Προτιμώ να παίζω με άλλους
- Δεν μ’αρέσουν τα παιχνίδια!

Q18 Αν σου αρέσουν τα συνεργατικά παιχνίδια, σου αρέσει να παίζεις στο Internet ή παρέα με φίλους σου στο ίδιο μέρος;
- Μ’αρέσει να παίζω στο Internet
- Δεν με νοιάζει
- Προτιμώ να παίζω με παρέα
- Δεν μ’αρέσουν αυτά τα παιχνίδια!

Q19 Πόσο σε ενδιαφέρει η ελαιοπαραγωγή;
- Καθόλου
- Λίγο
- Αρκετά
- Πολύ
- Πάρα πολύ

Q20 Πόσο καλά πιστεύεις πως γνωρίζεις τη διαδικασία ελαιοπαραγωγής;
- Καθόλου
- Λίγο
- Αρκετά καλά
- Πολύ καλά
- Πάρα πολύ καλά
Appendix A: Experiment Documents

Q21 Έχεις επισκεφτεί κάποιο ελαιοτριβείο με το σχολείο ή την οικογένειά σου;
- Με το σχολείο μου
- Με την οικογένειά μου
- Και με τους δύο
- Ποτέ

Q22 Τι περιμένεις περισσότερο από τη σημερινή σου επίσκεψη στο μουσείο;
- Να παίξω ένα διασκεδαστικό παιχνίδι
- Να μάθω για την ελαιοπαραγωγή
- Να απολαύσω το μουσείο
- Τίποτα/Δεν ξέρω
- Αλλά: ____________________
ΕΡΩΤΗΜΑΤΟΛΟΓΙΟ ΕΜΠΕΙΡΙΑΣ  {Experience Questionnaire}

Q1 Σευχαριστούμε που έπαιξες με το Εικονικό Ελαιοτριβείο. Με αυτό το σύντομο ερωτηματολόγιο θα μπορέσεις να εκφράσεις πως ένιωσες στο παιχνίδι.

Q2 Αρχικά, γράψε παρακάτω το κωδικό όνομα που επέλεξες να χρησιμοποιήσεις στο παιχνίδι:

Q10 Σε κάθε μια από τις παρακάτω προτάσεις, σημείωσε πώς ένιωσες παίζοντας το παιχνίδι. Φέρε την εμπειρία πάλι στο μυαλό σου και απάντησε όσο πιο ειλικρινά μπορείς.

<table>
<thead>
<tr>
<th>Με ενδιέφερε η υπόθεση του παιχνιδιού</th>
<th>Καθόλου (1)</th>
<th>Λίγο (2)</th>
<th>Μέτρια (3)</th>
<th>Αρκετά (4)</th>
<th>Πάρα πολύ (5)</th>
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<td>Ένιωσα σιγουριά καθώς έπαιζα</td>
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<td>Βαρέθηκα</td>
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<td>Καθώς έπαιζα, ξέχασα τα πάντα γύρω μου</td>
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<td>Το παιχνίδι δεν πήγε όπως ήθελα</td>
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<td>Το βρήκα κουραστικό</td>
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<td>Ένιωσα καλά παίζοντας</td>
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<td>Χρειάστηκα να καταβάλω μεγάλη προσπάθεια στο παιχνίδι</td>
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<td>Το παιχνίδι με έκανε νευρικό</td>
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<td>Ήμουν καλός στο παιχνίδι</td>
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</table>
### Q13 Τώρα, σκέψου την επίσκεψή σου στο μουσείο και απάντησε τις παρακάτω ερωτήσεις:

<table>
<thead>
<tr>
<th>Ερώτηση</th>
<th>Καθόλου (1)</th>
<th>Λίγο (2)</th>
<th>Μέτριο (3)</th>
<th>Αρκετά (4)</th>
<th>Πάρα πολύ (5)</th>
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<tbody>
<tr>
<td>Η επίσκεψη στο μουσείο πήγε όπως περίμενε.</td>
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<td>Αυτά που έμαθα με ενδιέφεραν</td>
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<td>Οι πληροφορίες που έμαθα είναι χρήσιμες</td>
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MEMORANDUM

DATE: May 12, 2015

TO: Doug A Bowman, Panagiotis Apostolakis

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)

PROTOCOL TITLE: C-OLIVE III: Audience interaction for increased student involvement and learning

IRB NUMBER: 15-150

Effective May 7, 2015, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 6,7

Protocol Approval Date: May 7, 2015

Protocol Expiration Date: May 6, 2016

Continuing Review Due Date*: April 22, 2016

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution
Appendix A: Experiment Documents

Recruitment Flyer for Teachers

Collocated Collaborative Game-Based Learning with Virtual Environments in Museums

Panagiotis Apostolellis (panaga@vt.edu) and Doug A. Bowman (bowman@vt.edu)

Scope of Research:

- Facilitate group learning in museums
- Impact of group interaction on learning
- Impact of group interaction on engagement
- Understand benefits of collocated collab
- Visiting - game experience relationship

Game specifics:

- Tripartite collaboration
- Individual virtual world viewpoints
- Commercial game controllers (Xbox)
- Encourage player collaboration
- Discovery learning through game play

Results from two studies:

- Positive effect of collab on learning
- Collaboration increases positive affect
- Increased empathy due to social presence
- Facilitation improved understanding
- Equal interaction promotes engagement
- Kids enjoy playing together

Future Plans:

- Involve a larger audience (classroom)
- Explore audience interaction technologies
- Measure effects on learning
- Measure effects on sustained engagement
- Shorter game duration and practice
Study Procedure in MCPS Classrooms

The study will be conducted with the help of the teacher (you!), in three different days, exclusively within the school grounds (inside the classroom). It involves the whole classroom, playing a computer game about industrialized olive oil production. Students will be immersed in a virtual olive oil factory and will have to operate the machinery involved (steam engine, presses, pumps, mills) in order to produce olive oil! The study will need to be conducted within the Fall semester.

Initially, you will need to distribute and gather the parental permission forms for all students who would like to participate in the study. No student can participate in the study with two different groups; we will need to arrange some activity to occupy the duplicate students. During the first day, approx. one week ahead of the pre-arranged study date, the students will be introduced to the study by the researchers. During this time they will be called to complete an online background questionnaire and a quiz about olive oil production (pre-test), using the provided iPads, if they agree to participate (verbal assent). No other activity will be taken during the first day.

The second day will include the actual game play, which involves a large front-projected screen and interaction devices (i.e., Xbox controllers and iPads). Students will initially be introduced to the experimental procedure and then watch a 5-minute video about the olive oil production and the machinery involved. Then, two randomly chosen students (with high video game skills, taken from the background survey) will get to use the game controllers (thereafter called the ‘players’), while the rest of the classroom (the ‘audience’) will be handed with the iPads. A brief practice session will allow all students to get accustomed with the interaction devices, the game interface, and the style of collaboration between them. This session will include two simple tasks that players will have to complete either by themselves, or with the assistance of the audience.

After the practice is over, the main trial (game) will begin. Classrooms will be assigned randomly between two different experimental conditions, varying the level of audience involvement in the game (HI=high; LI=low). The audience will get to sporadically respond to questions presented on the screen by using their iPads. In the HI condition their responses will assist the players in completing the tasks. In the LI condition, they will have to attend to the game and promptly register when a task is performed; they will be competing with other classes and between each other in pairs, as a means of increasing motivation.

Right after the game, all students will get to complete a questionnaire measuring their game experience and feelings of interconnectedness with their peers. They will be thanked for their participation and awarded a certificate of game completion, documenting their performance in the game. A brief semi-structured interview with the teacher will follow the game or take place right after the school hours, on the same day or the day following the study. The teacher will be thanked for his contribution to our research with a $25 gift card for buying classroom supplies.

The third, and last, day will be the day immediately following the study, where students will be called to complete the exact same quiz (post-test). The difference between their scores will be used as a measure of their learning gains, attributed to the game intervention. Last, we will conduct an informal interview with some of the students, if the time and the class schedule allows.

Thank you for considering your participation in our study. For any inquiries please contact: Panagiotis Apostolellis (panaga@vt.edu) or Dr. Doug Bowman (bowman@vt.edu)
Dear Sir/Madam,

We are delighted to be able to offer your child the opportunity to participate in a study about social game play in virtual reality environments. This is an innovative study in which we employ state of the art technology to engage the whole classroom at the same time with an educational game about olive oil production. We are interested in understanding the benefits of co-located collaborative play of middle-school children in informal learning settings, like science museums. Your child will have the unique opportunity to find out about the process of olive oil extraction and the machinery involved, by watching a 3D movie and then playing a 3D game with his/her classmates on a projector screen, using Xbox game controllers and iPads.

This opportunity has been provided because of a partnership between the Montgomery County Public Schools (MCPS) and the Center for Human Computer Interaction, Dept. of Computer Science at Virginia Tech. Your child’s teacher has agreed to offer this opportunity to his/her classes and we would be very happy if you gave permission to your child to participate. If you are interested you need to read and sign the attached “Parental Permission” form, and return it to the teacher within a week from today. The study will be scheduled in collaboration with the teacher, in order to fit his/her class schedule.

**Brief description of the study:**
The study will take place during three school hours, in different days. During the first and last day students will be called to complete some surveys; these include collecting demographic data, measuring their knowledge about the subject matter (olive oil production process), and measuring their subjective game experience. The middle day they will watch a brief video and then get to play the game with their peers in the classroom. For a more detailed description of the procedure, please read the paragraph “II. PROCEDURES” included in the attached Parental Permission form.

We anticipate that you will find this opportunity very interesting for your child, granting him/her permission to participate in our study. If you have any questions, please do not hesitate to contact me.

Sincerely,

Panagiotis Apostolellis
PhD Candidate of Computer Science, Virginia Tech
e-mail: panaga@vt.edu
Experiment III

Parental Permission for Participant of Investigative Project
Virginia Polytechnic Institute and State University

Title of Project: **C-OLiVE III: Audience interaction for increased student involvement and learning**

Investigators: Dr. Doug A. Bowman, Panagiotis Apostolellis

I. **THE PURPOSE OF THIS RESEARCH/PROJECT**

We are inviting your child to participate in a study where we evaluate social game play of a whole classroom in a virtual world, with the intent to understand if active audience involvement with the game affords greater learning. This research constitutes a study of two different setups where middle school students play together as a classroom, in order to learn about olive oil production in the Industrial Era. The game will be displayed on a large projected display inside the classroom, and students will be using a combination of Xbox game controllers and iPads.

II. **PROCEDURES**

Initially, you will have to read, sign, and return this form to the teacher before your child is allowed to participate in this study. The study will be conducted with the teacher’s assistance, in three different days, exclusively within the school grounds (most probably inside the classroom). Initially, we will introduce the research to the students, one week ahead of the pre-arranged study date (i.e., the date they will get to play the game). During this time students will be called to complete an online background questionnaire and a quiz about olive oil production, if they assent to participate. No other activity will be taken during this first day.

The second day will include the actual game play, which involves a large front-projected screen and interaction devices (i.e., Xbox controllers and iPads). Students will initially be introduced to the experimental procedure and then watch a 5-minute video about the olive oil production and the machinery involved. Then, the students will be split in different groups with distinct roles in the game, using one of the two devices. A brief practice session will allow all students to get accustomed with the interaction devices, the game interface, and the style of collaboration between them. After the practice is over, the main trial will begin. Each classroom will be assigned randomly between two different experimental conditions, varying the level of audience involvement in the game. Some classes will be selectively recorded and/or photographed for documentation purposes (no face blurring will occur unless requested). Right after the game, all students will get to complete a questionnaire measuring their game experience and feelings of interconnectedness with their peers. They will be thanked for their participation and awarded (as a class) a certificate of game completion, documenting their performance in the game. Some competitive elements might be also used between student pairs and between classrooms, as a means to increase student motivation.

The third, and last, day will be the day immediately following the study, where students will be called to complete a post-test, with exactly the same questions as the pre-test. The difference between their scores will be used as a measure of their learning gains, attributed to the game intervention. Last, we will conduct an informal interview with some of the students, if the time and class schedule allows.

III. **RISKS**

There will not be more than minimal risks involved in our study.

IV. **BENEFITS OF THIS PROJECT**

By providing permission for your child to participate in this study you will help us gather valuable information about prospective benefits of digital technology, more specifically virtual reality environments, for collaborative game-based learning in the classroom but also in informal education settings, such as museums and science centers. No guarantee of benefits has been made to encourage your child to participate. You may receive a synopsis summarizing this research when completed, upon request.
V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

In the process of the research, your child might be photographed as part of the whole classroom, with the sole purpose of documenting the setup and using it for teaching and research purposes (professional meetings and scholarly publications). Your child’s name or any other personal information will not be recorded and a self-chosen code name (pseudonym) will be used throughout data collection and results reporting to identify him/her as a participant, as a means of preserving anonymity and confidentiality. All data will be maintained indefinitely on the investigators’ password-protected computers and/or in a locked office of one of the investigators. You have the right to review the tapes and photographs made as a part of the study to determine whether they should be edited or erased in whole or in part.

It is possible that the Virginia Tech Institutional Review Board (IRB) may view this study’s collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. COMPENSATION

Participation in this study is voluntary and unpaid. Candies might be used as a reward to participating students.

VII. FREEDOM TO WITHDRAW

You may withdraw your child from the research project at any time and for any reason. Your child is free to not answer any questions without penalty. To withdraw, please inform the teacher or one of the “investigators” listed at the bottom of this form.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science. Virginia Tech IRB Approval number: 15-150.

IX. PARENT OR GUARDIAN’S PERMISSION

I voluntarily agree to permit my child to participate in this study, and I know of no reason s/he cannot participate. I have read and understand the parental permission and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary permission for his/her participation in this project. If s/he participates, s/he may withdraw at any time without penalty. I agree to abide by the rules of this project.

________________________________________________________________________
Signature
________________________________________________________________________
Date
________________________________________________________________________
Full name (please print)
________________________________________________________________________
Contact: e-mail
Informed Consent for Participant of Investigative Project
Virginia Polytechnic Institute and State University

Title of Project: C-OLiVE III: Audience interaction for increased student involvement and learning

Investigators: Dr. Doug A. Bowman, Panagiotis Apostolellis

I. THE PURPOSE OF THIS RESEARCH/PROJECT
You are invited to participate in a study where we evaluate social game play of a whole classroom in a virtual world, with the intent to understand if active audience involvement with the game affords greater learning. This research constitutes a study of two different setups where middle school students play together as a classroom, in order to learn about olive oil production in the Industrial Era. The game will be displayed on a large projected display inside the classroom, and students will be using a combination of Xbox game controllers and iPads. Your feedback about the social and computer-mediated interactions happening during the game and about the effectiveness of this approach, will help us understand how to improve the audience interaction design for engaging a large student audience with a topic, also increasing learning benefits.

II. PROCEDURES
The study will be conducted with your assistance, in three different days, exclusively within the school grounds (most probably inside your classroom). Parental permission should be obtained before the first day to allow students to participate in the study. Initially, we will introduce the research to the students, one week ahead of the pre-arranged study date (the date will have to be decided early enough to facilitate scheduling). During this time students will be called to complete an online background questionnaire and a pre-test, using the class computer equipment, if they agree to participate. No other activity will be taken during this first day.

The second day will include the actual game play, which involves a large front-projected screen and interaction devices (i.e., Xbox controllers and iPads). Students will initially be introduced to the experimental procedure and then watch a 5-minute video about the olive oil production and the machinery involved. Then, you have to select two volunteers that will get to use the game controllers (thereafter called the “players”), while the rest of the classroom (the “audience”) will be handed with the iPads and be seated at the back of the players. A brief practice session will allow all students to get accustomed with the interaction devices, the game interface, and the style of collaboration between them. This session will include two simple tasks that players will have to complete either by themselves, or with the assistance of the audience.

After the practice is over, the main trial will begin. Each classroom will be assigned randomly between two different experimental conditions, varying the level of audience involvement in the game. The audience will get to sporadically respond to questions presented on the screen by using their iPads; their responses will assist the players in completing the tasks. At some points the audience might also serve as a third player, using the aggregate of their responses (majority rule) to perform some action(s) with the players.

Right after the game, all students will get to complete a questionnaire measuring their game experience and feelings of interconnectedness with their peers. They will be thanked for their participation and awarded (as a class) a certificate of game completion, documenting their performance in the game. You will then have to respond to some questions about the experience, either following the game or right after the school hours.

The third, and last, day will be the day immediately following the study, where students will be called to complete a post-test, with exactly the same questions as the pre-test. The difference between their scores will be used as a measure of their learning gains, attributed to the game intervention. Last, we will conduct an informal interview with some of the students, if the time and your class schedule allows.

III. RISKS
There will not be more than minimal risks involved in our study.
Appendix A: Experiment Documents

IV. BENEFITS OF THIS PROJECT

By agreeing to participate in this study and giving us permission to run the experiment with your classes, you will help us gather valuable information about prospective benefits of digital technology for large-group collaboration using games and virtual worlds, for learning in informal education settings. These insights can also be used in the future for the development of more advanced technologically enhanced instructional approaches for the whole classroom. No guarantee of benefits has been made to encourage you to participate. You may receive a synopsis summarizing this research when completed, upon request.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

In the process of the research, we will only record the interview at the end of each game session with a class. We will not gather any personal data from students. We might take a few pictures at the back of a class to be used for illustration purposes, only. All data, including images and recordings, will be maintained indefinitely on the investigators’ password-protected computers and/or in a locked office of one of the investigators. You have the right to review the tapes and photographs made as a part of the study to determine whether they should be edited or erased in whole or in part. The investigators and research assistants will transcribe the interview recordings. Any data gathered from your or the students will be identified by a numbered code only, preserving anonymity and confidentiality. Only pseudonyms will be associated with reported results, protecting confidentiality.

It is possible that the Virginia Tech Institutional Review Board (IRB) may view this study’s collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. COMPENSATION

Your participation in this study is voluntary and will be rewarded with a $25 gift card from Amazon to be used for purchasing classroom supplies.

VII. FREEDOM TO WITHDRAW

You may withdraw any of your classes from the research project at any time and for any reason. You are free to not answer any questions during the interview without penalty. To withdraw, please inform one of the investigators listed at the bottom of this form.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science. Virginia Tech IRB Approval number: 15-150.

IX. INFORMED CONSENT

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary permission for my participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

________________________  ______________________
Signature                  Date

________________________  ______________________
Name (please print)         Contact: e-mail

________________________
Contact: phone or address (optional)
Should you have any questions about this study, you may contact one of the research investigators:

Research Investigators:  Dr. Doug A. Bowman  Phone (540) 231-2058
                      Professor, Computer Science Department
                      email: dbowman@vt.edu
                  
                      Panagiotis Apostolellis  Phone (540) 449-9254
                      Graduate Student, Computer Science Department
                      email: panaga@vt.edu

Should you have any questions or concerns about the study’s conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact:

VT IRB Review Board:  Dr. David Moore  Phone (540) 231-4991
                    Chair, Virginia Tech Institutional Review Board
                    For the Protection of Human Subjects
                    Email: moored@vt.edu
BG Survey | C-OLiVE III

Q1 Thank you very much for taking part in the "Virtual Olive Oil Factory" game! First of all you have to choose a code name which you are going to use during the game, but also for every form you complete (like this one). Make sure you write this code name somewhere and bring it with you when you join us!

Code Type your chosen code name below (maximum 12 letters):

Q34 Have you completed this questionnaire and/or played the Virtual Olive Oil Factory game before?
  ☐ No
  ☐ Yes

If Yes Is Selected, Then Skip To End of Survey

Q32 Great! Now, please help us learn some important things about you by completing the following items.

Gender What is your gender?
  ☐ Boy
  ☐ Girl

Q4 How old are you?
  ☐ 11
  ☐ 12
  ☐ 13
  ☐ 14
  ☐ Other ____________________

Q5 What is your school grade?
  ☐ 6th
  ☐ 7th
  ☐ 8th
  ☐ Other ____________________

Q8 How many hours a day do you use computers?
  ☐ None
  ☐ 0-1
  ☐ 1-3
  ☐ 3-6
  ☐ 6 or more
Q9 Do you play computer games (on any kind of device)?

☐ No
☐ Yes

Display This Question:
If Do you play computer games (on any kind of device)? Yes Is Selected

Q33 Which device(s) are you mostly using when playing games?

☐ Personal Computer (PC)
☐ iPad / iPod or other tablet
☐ iPhone or other smart phone
☐ Game console (e.g., Nintendo, Xbox, etc.)
☐ Other (please specify): ____________________

Q10 On average, how many hours a day do you play computer games?

☐ None
☐ 0-1
☐ 1-2
☐ 2-3
☐ 3 or more

Q11 Have you used an Xbox, Playstation or similar controller when playing video games?

☐ No
☐ Yes

Display This Question:
If Have you used an Xbox, Playstation or similar controller ... Yes Is Selected

Q12 If yes, which game platform(s)/controller(s) have you used?

☐ Microsoft Xbox
☐ Sony Playstation
☐ Nintendo Wii
☐ Microsoft Kinect
☐ Other (please specify): ____________________

Q13 How do you feel about computers and video games, in general?

☐ I don't like them
☐ I don't care
☐ I like them a lot
Appendix A: Experiment Documents

Q14 Have you ever played any computer games with a 3-dimensional world (e.g., Minecraft, Halo, CoD, etc.)?
☐ No
☐ Yes

Display This Question:
   If Have you ever played any computer games with a 3-dimensio... Yes Is Selected

Q15 If yes, which game(s)?

Q16 Have you ever experienced a virtual reality (VR) system that made you feel like you were inside the virtual world being displayed? (e.g., planetarium, theme park ride, etc.)?
☐ No
☐ Yes

Display This Question:
   If Have you ever been in a virtual reality environment whe... Yes Is Selected

Q17 If yes, describe the type(s) of technology the VR system used (e.g., large displays, head-mounted displays, 3D glasses, 3DTVs, etc.)

Q18 Have you ever played a game on a screen larger than your home TV?
☐ No
☐ Yes

Display This Question:
   If Have you ever played a game in a screen larger than y... Yes Is Selected

Q19 If yes, what kind of display was that (e.g., wall projector)?

Q20 Have you played a computer game together with friends next to each other, where you had to collaborate in order to succeed in the game? (e.g., Mario Kart)
☐ No
☐ Yes

Display This Question:
   If Have you played a computer game together with friends whe... Yes Is Selected

Q21 If yes, which game(s)?

Q22 Have you played any multiplayer online game with other people (like Facebook games, Minecraft, World of Warcraft, Second Life, etc.)?
☐ No
☐ Yes
### Experiment III

<table>
<thead>
<tr>
<th>Display This Question:</th>
<th>If Have you played any multiplayer online game with other ... Yes Is Selected</th>
</tr>
</thead>
</table>

Q21 If yes, which game(s)?

Q24 How do you feel about playing computer games with friends and family?
- I prefer playing alone
- I don't care
- I prefer playing with others
- I don't like games!

Q25 If you like multi-player games, do you like to play online or together with friends at the same place?
- I prefer playing online
- I don't care
- I like to play together
- I don't like these games!

Q26 How much do you know about olive oil and how it is produced?
- Not at all
- A little bit
- Enough
- Very well
- Perfectly

<table>
<thead>
<tr>
<th>Display This Question:</th>
<th>If How much do you know about olive oil and how it is produced? Perfectly Is Selected</th>
</tr>
</thead>
</table>

Q27 Please describe what do you know:

Q28 How much do you know about how machines like stone mills, boilers, engines, presses, and pumps work?
- Not at all
- A little bit
- Enough
- Very well
- Perfectly

<table>
<thead>
<tr>
<th>Display This Question:</th>
<th>If How much do you know about how machines like stone mills, boilers, engines, presses, and pumps work? Perfectly Is Selected</th>
</tr>
</thead>
</table>

Q29 Please describe what do you know:
Pre-test Quiz | C-OLiVE III

Q1 This is a brief quiz about industrialized olive oil production during the 1960s. Your answers will help us understand your knowledge level on the topic, before you join us and experience the Virtual Olive Oil Factory game.

Q2 Please, type the exact same code name that you chose to use in the game:

Q3 Please respond to the following questions to the best of your knowledge. If you do not know the answer to any of the questions, select the “I don’t know” option instead of guessing.

Q4 How did the olive oil factory provide power to the machines involved in production?
   ☐ Using petroleum
   ☐ Using steam
   ☐ Using manpower
   ☐ Using horse power
   ☐ I don’t know

Q5 What was the fuel that was used to heat the water inside the boiler?
   ☐ Coal
   ☐ Copper
   ☐ Firewood
   ☐ Olive pomace
   ☐ I don’t know

Q6 How was the power transmitted from the engine to the rest of the factory?
   ☐ Through electricity
   ☐ Through belts and pulleys
   ☐ Through water pipes
   ☐ Through steel wires
   ☐ I don’t know

Q7 Why was it necessary to have two workers in order to fill the mills with olives?
   ☐ Because the olive sacks were located far away from the mills
   ☐ Because the olive sacks were too heavy
   ☐ Because the mills were too high
   ☐ Because one worker had to hold the mill’s lid open
   ☐ I don’t know
Q8 What happened to the pit and the skin of the olives?
- They were part of the produced edible olive oil
- They remained on the fiber mats after pressing
- They were removed before grinding
- They were discarded during the separation process
- I don’t know

Q9 How was olive oil quality affected during the grinding process in the mills?
- Prolonged grinding without watering down increased heat of the olive pulp
- The pulp contained other substances which were transferred to the oil
- Too many olives were loaded in the mills
- The mill’s wheels were turning at a lower speed than appropriate
- I don’t know

Q10 How many straw mats with olive pulp should each press have had before pressing would start?
- At least 40
- No more than 40
- Until it was fully-loaded
- Until it was half-loaded
- I don’t know

Q11 What did the workers have to do to release a press after the process was finished?
- Release the lever that gave power to the press
- Wait until the press would release itself automatically
- Move the belt of the corresponding pump back to the idle pulley
- Close the hydraulic valve of the corresponding pump
- I don’t know

Q12 How was the unfiltered oil transferred from the presses to the oil separators?
- Using an oil pump and a system of pipes and oil gathering tanks
- Using a small cart where the press tanks were loaded
- Manually, using buckets which were emptied in bigger tanks
- There was no need because the separators were next to the presses
- I don’t know

Q13 How did the DeLaval separators separate the pure olive oil from the water?
- Using centrifuge power at high revolutions per minute (rpm)
- Using a system of pipes and vessels
- Using specialized chemical substances
- Using inertia where liquids were separated due to density difference
- I don’t know
Appendix A: Experiment Documents

Q14 Why might someone use a small cart in the olive press factory?
- To load the fuel inside the boiler furnace
- To load the olives from the sacks inside the mills
- To transfer the unfiltered olive oil near the separators
- To transfer the olive pulp from the mills to the press loading table
- I don’t know

Q15 Why did all machines in the factory use two pulleys?
- As a backup, in case one of them broke down
- To select the speed of machine operation
- To start/stop operation of the machine
- To maintain a steady rotation speed
- I don’t know

Q16 Which two machines must be working at all times in order for the factory to operate?
- Boiler and press
- Engine and mill
- Engine and press
- Boiler and engine
- I don’t know

Q17 Where did the water coming out of the DeLaval separators come from?
- The water was used by the separator to prevent overheating
- The water is part of the olives themselves (vegetation water)
- It was the water added during the grinding process
- It came both from the olives and the amount added during grinding
- I don’t know

Q18 What might have caused the press tray to break?
- Uneven load of the press tray with mats
- Increased pressure from the pump to the press
- Either or both of the above at the same time
- None of the above; the press tray was unbreakable
- I don’t know

Q19 What happened with the remains of the pulp in the mats after the pressing process?
- They were disposed
- They were used as fuel in the boiler
- They were consumed by the workers
- They were pressed again to produce more oil
- I don’t know
Q20 Which of the olive oil factory workers had to start work earlier in the day?
- The ones in charge of loading the mills with olives
- The ones who were maintaining the engine
- The ones in charge of starting up the boiler
- The ones who were loading the presses
- I don’t know

Q21 How many workers were needed in order to...

<table>
<thead>
<tr>
<th>Task</th>
<th>One</th>
<th>Two</th>
<th>I don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load and ignite the boiler</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Load the mills with olives</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Transfer the olive pulp from the mills to the loading table</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Load the mats with the olive pulp</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Load the presses with mats</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Operate the pump</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Attach belts to machines</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Load the unfiltered oil in the separators</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Transfer the oil containers to the scale</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Maintain a constant steam pressure to the engine</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
</tbody>
</table>

Q22 For the following two questions, please provide as accurate a response as possible according to your current knowledge.

Q23 Describe the process involved in getting the unfiltered olive oil from the olive pulp giving as many details as possible about machines and workers involved (if you don’t know leave it blank):

Q24 Describe the necessary tasks and machine operations that workers had to do in order to provide power to the olive oil production factory machinery (if you don’t know leave it blank):
Appendix A: Experiment Documents

Experience Questionnaire | C-OLiVE III

Q11 Hey {code name completed automatically}, thanks for playing the Virtual Olive Oil Factory Game! This brief questionnaire will allow you to express how the game make you feel. Think back to the experience and respond as truthfully as possible.

Q2 Type your code name, if it is not already filled in.

Q9 Select if you played the game using an iPad or an Xbox controller:
- iPad
- Xbox

Q10 For each of the following, please indicate how you felt while playing the game.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>Slightly</th>
<th>Moderately</th>
<th>Fairly</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>I was interested in the game's story</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt confident while playing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt bored</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found the game impressive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>While playing, I forgot everything around me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing the game did not go as I wanted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found it tiresome</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt good while playing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I had to put a lot of effort into the game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The game made me nervous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I paid a lot of attention to the game</td>
<td>I felt challenged by the game</td>
<td>I was good at it</td>
<td>I thought it was fun to play the game</td>
<td>I enjoyed a lot playing with others</td>
<td>It was easy for me to work with my peers</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------------------------</td>
<td>-----------------</td>
<td>--------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>connected to the others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I paid close attention to the others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt jealous about the others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My actions depended on the others actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The others’ actions were dependent on my actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What the others did affected what I did</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What I did affected what the others did</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was ashamed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was shy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Child-Appropriate Narrative Explaining the Study

<table>
<thead>
<tr>
<th>Begin</th>
<th>-</th>
<th>We assume that all students who plan to participate have delivered their signed parental permission forms ahead of time.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong></td>
<td><strong>Introduction</strong></td>
<td>1’</td>
</tr>
<tr>
<td></td>
<td><strong>Explanation</strong></td>
<td>1’</td>
</tr>
</tbody>
</table>
| | **Walkthrough** | 5’ | I will now briefly walk you through the process of this study, which involves three days, and would like you to let me know if you have any questions, at any point. OK?  

Today you will have to do two things: first, complete a questionnaire with some questions about you and your game experience and preferences. Then, you will take a quiz, so we can see how much you know about olive oil production. It is *very important* that you only respond to the questions you know, otherwise you should select “I don’t know.”  

In a week from today, you will get to play the actual game as a classroom. You are not expected to know how olive oil is produced, so you will first watch a brief video explaining the process. Then, you will practice a little bit with the game and, when you feel comfortable, you will start playing. At the end of the game you will need to complete a short questionnaire about your impression of the experience. If we have time left, I would also like to hear your opinions by having a brief discussion with whoever wants to share them with me.  

The day after playing the game, I will come back and give you the quiz again. The only thing you will have to do then is to try and remember what you have learned from the video and playing the game in responding to the questions. I will also award a certificate of completing the game to all of you as a classroom. You will not receive any kind of grade on your results and your performance has no connection whatsoever with your school grade. Do you have any questions? |
| **Withdraw** | 1’ | The whole process takes approximately two half classes (for the questionnaires) and a full class hour (for the game), depending on how fast you finish the game. You can stop at any time! You can also take a break, or you can withdraw from the study at any time, for any reason or no reason at all. |
| **Assent** | - | Do you all agree with our terms? *<get verbal assent and proceed>* |
**Experiment III**

<table>
<thead>
<tr>
<th>Code name</th>
<th>1’</th>
</tr>
</thead>
</table>
| We will keep your identity secret, this is why we would like you to use a code name throughout this study. All of your results will be saved under this code name, so it is very important to remember it whenever requested, either in completing the online forms or while playing the game. Please, choose your preferred code name now, and make sure you keep a note of it. |<give them time to think about the code name and tell them make a note in the provided post-it>

<table>
<thead>
<tr>
<th>Survey &amp; Pre-test</th>
<th>15’-20’</th>
</tr>
</thead>
</table>
| Now is the time to start filling out these online forms. You will use these iPads to first complete the background survey and then take the quiz about olive oil production. I want to remind you again that it is very important to respond only to the questions you know about. Guessing will give me the wrong data and will not be helpful at all. It is absolutely normal not to know most, if not all, of the questions, in which case please select the option “I don’t know.” |<provide the iPads and load the survey link – click ‘[’ in Vizard>

<table>
<thead>
<tr>
<th>Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup the projection and seat arrangement before classroom starts.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Introduction</th>
<th>1’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hello again. I am glad to see all of you. This is the fun day! As I told you last week, we will start by watching a video about olive oil production, then play the game, and finally complete a questionnaire. Are you ready to start?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Video</th>
<th>5’</th>
</tr>
</thead>
</table>
| You will now watch a 5-min video describing the operation of an olive oil factory with all the main processes explained. Please, try to pay as much attention as possible to the information provided, because it will help you understand how the factory works and make your life easier while playing the game. It will also help you when taking the quiz tomorrow. |<Play the video>

<table>
<thead>
<tr>
<th>Condition</th>
<th>1’</th>
</tr>
</thead>
</table>
| Well, here is how the game works. Two of you, who have been randomly selected from the forms you completed last week, will get to play the game using these Xbox controllers. The rest of you are: |<Announce code names, place them in the front seats, and hand in controllers; start game: enter group # and player names>

| HI | still going to interact with the game and help the players succeed, using these iPads. |
|    | <Hand them the iPads with C-OLiVE MCPS open and guided access enabled>

<table>
<thead>
<tr>
<th>Explanation</th>
<th>2’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Let me explain your roles: Your goal is to operate the machinery in the factory (these green symbols) and produce olive oil; when one can of olive oil has been produced the game is finished. In order to do this, you need to attend to all the alert messages (yellow) and information (blue) that pop up, and troubleshoot problems as promptly as possible. When performing a task you will get feedback on the side bar and awarded points if the action is correct. I would like you to recall the information in the video and try out as many actions as possible; in case you are stuck I will be here to assist you, but try to work together as closely as possible.</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix A: Experiment Documents

| & iPad login | <Audience> You will get to…<LI> attend to the game at all times and provide your feedback to the prompts on the iPads, as quickly as possible. This will increase your score as a classroom in the first part of the game (steam production), and rank you higher in the top scorers in the second part (olive oil production), where you’ll be playing in pairs. <HI> work all together to help the students controlling the game perform all the necessary operations in order to produce olive oil, by following the prompts on your iPads and the top-left of the projection screen. <All> Everyone should be paying attention to what’s happening in the game, trying to understand the olive oil production process. This will not only increase your score as a class but also give you an advantage when taking the quiz later. Do you have any questions? <Address any questions>Are you ready to play? Let’s connect! <Prompt all audience members to connect using their code names; check if they all remember them>

| Main Trial | Max. 40’<...While they connect...> Before we begin, I want to make sure that everyone understands the game and how to play using the devices you are holding. This is why I will walk you through troubleshooting the first problem. I want you to pay close attention to my instructions and after you understand how everything works, I will let you play by yourselves. The audience will have to wait until you receive instructions on the iPads to do something. Try to be as responsive as possible. <Start the game and follow the practice script> Is everything clear?

| Game Experience Survey | 5’<After game is done> Great! I would like each one of you to take the brief survey that will appear on your iPads about how the game made you feel. Please, write your responses by being as truthful as possible. Remember that these responses are used to evaluate the game, not you, so please be relaxed <Click ‘.’ to load the game experience questionnaire on their iPads>

| Day 3 | 

| Post-test | 15’Hi again. Now is time for you to take the quiz with general questions about the information you show in the video and the game. Try to remember and think as much as possible about the actions and tasks that were performed in the virtual factory before answering the questions. If you don’t know an answer, please select “I don’t know” instead of guessing, as this will allow us to record exactly what you have learned.<Click ‘}’ to load the post-test and hand them the iPads>

| Interview with teacher | 15’<...While students take the post-test...> I would like you to respond to some questions, about your impression for the experience your classes had while playing the game yesterday. I would like to record this conversation, if you don’t mind. <Start recording and follow interview script>Thank you for offering your valuable time for my study. I hope you found this to be a rewarding educational and entertaining experience for your classes. This is a small gift of appreciation to be used for class supplies. <Award the gift card>

| Certificate | -Thank you for participating in our experiment. I am awarding you this certificate with your performance as a class, as a souvenir of your participation in the Virtual Olive Oil Factory game. Thanks again for your valuable assistance! |
Experiment III

Experiment Flow

Day 1 – Pre-test
1. Setup computer and test network
2. Request Parental Permission forms from the teacher
3. Read the Child Appropriate Narrative-Assent – Day 1 and show them olive branch and olive oil
4. Get verbal assent from participating students
5. Open the iPads and load the C-OLiVE MCPS app
6. Start Vizard and click '[' to load the BG Survey on the iPads
7. Enable Guided Access on iPads and hand them to students, with the post-it for noting the code
8. Wait until all students have completed both the BG Survey and Pre-test
9. Get all iPads back and thank students and teacher

Day 2 – Game play
1. Save the BG_Survey__COLiVE_III.csv with code names and gender and check for empty spaces
2. Get printed copy of BG_Survey__COLiVE_III.csv for the class (in case someone forgets code)
3. Setup projector and computer, change IP settings, test network, connect Xbox receiver & clicker
4. Start C-OLiVE on Vizard and select the right condition and group number [H1, L2, etc.]
5. Read the Child-Appropriate Narrative-Assent – Day 2 and start the introductory Video
6. [While video plays] Start the C-OLiVE MCPS app on the iPads and enable Guided Access
7. [After video finishes] Announce the Condition and the players chosen; enter names in Vizard
8. Begin the Power Point slide and start the Explanation; use clicker to highlight interface areas
9. Start the Xbox controllers; hand them to the players and the iPads to the audience members
10. Wait until all audience members are connected and press 'Start' in Vizard
11. Read Practice Script while guiding them through the game to solve the first problem (belt)
12. Explain the role of the audience depending on the condition
13. [A little before game finishes] Load the C-OLiVE app on two iPads and type ###1 and ###2
14. [When game’s done] Press ‘.’ to load the Game Experience Questionnaire on all iPads
15. Get all iPads back and thank students and teacher; remind them not to share information

Day 3 – Post-test
1. Setup computer and test network
2. Read the Child-Appropriate Narrative-Assent – Day 3
3. Open the iPads and load the C-OLiVE MCPS app
4. Open Vizard and click ‘]’ to load the Post-test on the iPads
5. Enable Guided Access on iPads and hand them to students
6. Conduct the Informal Interview with the teachers – start recording with the ZOOM microphone
7. Get all iPads back, thank students, and give them their C-OLiVE Certificate
8. Give $25 gift card to teacher and thank her personally

After the Experiment
Day 1. Download the BG_Survey__COLiVE_III.csv file with code name and gender only
Day 2. Backup Trial data to a different folder
Day 3. Download the .wav file from the ZOOM
Appendix A: Experiment Documents

Interview Questions for Teachers

Teacher: ____________________ Date: ___________

Please, respond to the following questions to the best of your knowledge and according to your observations of the students playing with the “Virtual Olive Oil Factory” game. If you are unsure or do not wish to respond to a question, you can request that we move forward.

What was your overall impression about the game?

Did you think your students enjoyed playing the game? The players or the audience enjoyed more?

Do you think the students could understand and interact easily with the game?

Do you consider this a valuable learning experience for your students? Why or why not?

What was the thing you liked the most about this interactive experience?
Experiment III

What did you dislike the most and why? How could it be improved?

Do you see this being used in the classroom? What about informal learning spaces, like museums?

Low
Were the players able to work together efficiently without distractions from the audience?

High
Were the students able to work together efficiently? Did the audience assist them adequately?

Other comments (incl. details about the teacher background, experience, etc.):
Appendix B: Case Study Material

Collection of all the material used during our case study at the Franklin Institute, including:

- VT IRB approval letter
- Process board
- 3d printed models
Appendix B: Case Study Material

MEMORANDUM

DATE: February 29, 2016

TO: Doug A Bowman, Panagiotis Apostolellis

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: C-OLIVE IV - Case Study: Involving the audience in informal learning contexts

IRB NUMBER: 16-187

Effective February 29, 2016, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 7
Protocol Approval Date: February 29, 2016
Protocol Expiration Date: February 28, 2017
Continuing Review Due Date*: February 14, 2017

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal/ work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

— Inven the Future —

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution
Figure B-1. Part of the printed Process Board for the initial stage of powering the factory: Steam production.
Figure B-2. Part of the printed Process Board for the first stage of the olive oil production process: Grinding.
Figure B-3. Part of the printed Process Board for the second stage of the olive oil production process: Pressing.
Figure B-4. Part of the printed Process Board for the third stage of the olive oil production process: Separation.
Figure B-5. The digital (left) and 3d-printed (right) form of the steam boiler.

Figure B-6. The digital (top) and 3d-printed (bottom) form of the steam engine.
Appendix B: Case Study Material

Figure B-7. The digital (left) and 3d-printed (right) form of the stone mill.

Figure B-8. The digital (left) and 3d-printed (right) form of the loading table.
Figure B-9. The digital (left) and 3d-printed (right) form of the press.

Figure B-10. The digital (left) and 3d-printed (right) form of the hydraulic pump.
Figure B-11. The digital (left) and 3d-printed (right) form of the oil pump.

Figure B-12. The digital (left) and 3d-printed (right) form of the oil storage tank.
Figure B-13. The digital (left) and 3d-printed (right) form of the Laval separator.

Figure B-14. The digital (left) and 3d-printed (right) form of the platform scale.
Appendix C: Audience Interaction Interface

Collection of the material illustrating the interface between the audience members and the game, including:

- List of tasks for the High Involvement condition (or Case Study) participants
- Interface screens of the iPads, for each task category
### Audience Interaction Tasks

<table>
<thead>
<tr>
<th>id</th>
<th>mach</th>
<th>task</th>
<th>type</th>
<th>quest</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>boiler</td>
<td>boiler_load</td>
<td>CHOICE</td>
<td>How can we start the boiler in order to heat the water and produce steam?</td>
</tr>
<tr>
<td>23</td>
<td>lavalR</td>
<td>belt_attach</td>
<td>IMAGE2</td>
<td>Can you recognize the types of pulleys used in the factory?</td>
</tr>
<tr>
<td>23</td>
<td>lavalR</td>
<td>belt_attach</td>
<td>IMAGE3</td>
<td>Which two pulleys do you need to connect before operating the DeLaval?</td>
</tr>
<tr>
<td>24</td>
<td>engine</td>
<td>engine_start</td>
<td>IMAGE1</td>
<td>How can we start the steam engine?</td>
</tr>
<tr>
<td>201</td>
<td>millR</td>
<td>mill_load</td>
<td>MAP</td>
<td>Where do you think the olives were stored to make loading the mills easier?</td>
</tr>
<tr>
<td>202</td>
<td>millL</td>
<td>mill_load</td>
<td>MAP</td>
<td>Where do you think the olives were stored to make loading the mills easier?</td>
</tr>
<tr>
<td>203</td>
<td>millR</td>
<td>pulp_water</td>
<td>MAP</td>
<td>Have you seen a watering can that can be used to dilute the pulp? Where?</td>
</tr>
<tr>
<td>204</td>
<td>millL</td>
<td>pulp_water</td>
<td>MAP</td>
<td>Have you seen a watering can that can be used to dilute the pulp? Where?</td>
</tr>
<tr>
<td>205</td>
<td>millR</td>
<td>mill_empty</td>
<td>IMAGE1</td>
<td>How can we get the olive pulp out of the mill?</td>
</tr>
<tr>
<td>206</td>
<td>millL</td>
<td>mill_empty</td>
<td>IMAGE1</td>
<td>How can we get the olive pulp out of the mill?</td>
</tr>
<tr>
<td>207</td>
<td>loader</td>
<td>pulp_transfer</td>
<td>MAP</td>
<td>Where is the olive pulp that needs to be transferred to the loading table?</td>
</tr>
<tr>
<td>209</td>
<td>loader</td>
<td>mat_load</td>
<td>IMAGE2</td>
<td>Identify the tasks that are necessary to fill the mats with olive pulp.</td>
</tr>
<tr>
<td>211</td>
<td>pumpR</td>
<td>pump_start</td>
<td>IMAGE1</td>
<td>How can we set the pump in motion?</td>
</tr>
<tr>
<td>212</td>
<td>pumpL</td>
<td>pump_start</td>
<td>IMAGE1</td>
<td>How can we set the pump in motion?</td>
</tr>
<tr>
<td>213</td>
<td>lavalR</td>
<td>laval_start</td>
<td>CHOICE</td>
<td>The DeLaval separator can be started similar to...</td>
</tr>
<tr>
<td>214</td>
<td>lavalL</td>
<td>laval_start</td>
<td>CHOICE</td>
<td>The DeLaval separator can be started similar to...</td>
</tr>
<tr>
<td>215</td>
<td>pressR</td>
<td>pump_stop</td>
<td>MAP</td>
<td>Which machine was used to control the pressing process? Where is it?</td>
</tr>
<tr>
<td>216</td>
<td>pressL</td>
<td>pump_stop</td>
<td>MAP</td>
<td>Which machine was used to control the pressing process? Where is it?</td>
</tr>
<tr>
<td>219</td>
<td>oilPump</td>
<td>oilPump_start</td>
<td>CHOICE</td>
<td>How can we set the olive pump in motion?</td>
</tr>
<tr>
<td>221</td>
<td>scale</td>
<td>pitcher_weigh</td>
<td>MAP</td>
<td>Where is the olive oil that needs to be transferred to the scale?</td>
</tr>
<tr>
<td>230</td>
<td>pumpR</td>
<td>rusty_valve</td>
<td>ACTION</td>
<td>Audience is helping turn the rusty valve and start pumping water to the press!</td>
</tr>
<tr>
<td>240</td>
<td>pressR</td>
<td>mats_align</td>
<td>ACTION</td>
<td>Audience is helping fully load the press with carefully aligned straw mats!</td>
</tr>
<tr>
<td>250</td>
<td>blueTanks</td>
<td>valve_open</td>
<td>ACTION</td>
<td>Audience is helping unscrew the valve and release the oil in the separator!</td>
</tr>
</tbody>
</table>

*Note: Tasks without a highlight are used only when both sets of machines operate in the game; pink tasks were used at the case study only.*
Figure C-1. Audience interaction task *CHOICE*.

Figure C-2. Audience interaction task *IMAGE1*; one of the options is selected.
Appendix C: Audience Interaction Interface

Figure C-3. Audience interaction task $IMAGE2$; each selected item describes the process depicted.

Figure C-4. Audience interaction task $IMAGE3$ (updated version of $IMAGE2$ used during the case study).
Figure C-5. Audience interaction task MAP; a point on the map is selected.

Figure C-6. Audience interaction task ACTION; tilting the iPad controls the rotation of the mat on the press.
Appendix D: Related Publications


