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

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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 this paper, we present our findings from a recent study in a museum in Greece, where triads of students had to learn about olive oil production using a game enabling different levels of interactivity and collaboration. We found that facilitation by an expert guide led to greater learning gains as compared to students playing alone, with one or three simultaneous game controllers. We also compared these results with a previous controlled experiment conducted in the US with middle school students, using the same game but without the ecologically valid facilitation. Drawing ideas from sociocultural and cognitive theories we interpret the contradictory findings, identifying the impact of culture on their (social) interactions, their subjective game experience, and eventually learning, in these spaces.

Author Keywords
Informal learning; game-based learning; prior knowledge; culture; co-located collaboration; interactivity; facilitation.

ACM CLASSIFICATION KEYWORDS
K.3.1 Computer Uses in Education: Collaborative Learning; H.5.3 Group and Organization Interfaces: Synchronous interaction.

INTRODUCTION
It is widely acknowledged that museums can provide opportunities for group learning, exploiting children's exposure to digital technologies like computer games [22]. 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. A need has been recognized [2] to study the impact of interactivity on learning, through extended engagement and self-directed inquiry, particularly for multiple users, when using science museum exhibits or any such experience.

Guided by this prompt, the primary goal of our work is to understand the impact of *interactivity* on learning in collaborative game play, during museum visits. In a first study with middle school students in a controlled environment, we found that tripartite co-located collaboration was associated with improved learning benefits over passively watching someone play a game [3]. However, this prior study ignored the possible impact of guided instruction in discovery learning settings. Thus, a second goal of this study is to assess the effect of *facilitation* by an expert guide on students' understanding of the presented material in the game, in a museum setting.

Moreover, most theories of instruction, whether formal or informal, are dissociated from the sociocultural profile of the learners. There is indeed a need to provide more options to students to choose their own way of learning; one that is designed to fit their sociocultural background [20]. 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. As a third goal, therefore, we attempt to identify how *cultural differences* (including assumed prior knowledge of the subject domain) can mediate the effects of interactivity on learning in museum spaces.

Following up on our previous study in the US [3], in this paper we report our findings from our second experiment with a different population, in a museum space in Greece. Our hypothesis was that culturally driven prior exposure to and interest in the subject would improve game experience and consequently learning, as these two variables were shown to be positively correlated in our first study. The results from both studies are compared and discussed in light of cultural and cognitive theories, concluding with preliminary guidelines for designing similar interactive exhibits for an inter-cultural museum audience.

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RELATED WORK

Evaluating the complex type of learning that happens in museums is challenging considering its informal and unstructured nature. Falk and Dierking, recognizing the importance of context in free-choice learning, suggested the Contextual Model of Learning (CML) for assessing informal learning experiences [8]. According to their model, there are three different contexts that play a significant role in this type of learning: the *personal*, the *social*, and the *physical*. Each one of these contexts contains some factors that need to be considered when designing and evaluating learning in museums; we discuss this further below.

Interactivity has been shown to be a significant component of visitor satisfaction by means of enabling multi-sensory dialogue, exploration/discovery, cultural connections, empowerment, uniqueness, and construction of meaning [1]. Moreover, games, as inherently interactive, have been widely used in museums to elicit and nurture curiosity, challenge, cooperation, choice, creativity, and discovery in museum visitors. The book *Museums at Play: Games, Interaction, and Learning* contains an impressive collection of work encompassing these themes, as they have been applied in fourteen different countries [4]. Nonetheless, no comparison of the visitors' attitudes, interests, and prior knowledge and their effect on learning between cultures has been reported in this, or any other work that we are aware of.

Most 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 [26]. Similarly, Kim and Bong reported cross-cultural differences in online collaborative behaviors among Finnish, American, and Korean undergraduate students [14]. In most cases, research is focused on the identification of design specifications for multi/cross-cultural online collaborative tools [9], and does not include the rich social interaction opportunities afforded by co-located 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 (field-independent vs. field-sensitive concept development), and according to the situation, task, or materials being used in the educational practice [6]. 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 [23]. 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.

The last point leads us to the importance of "scaffolding" during exploratory learning activities, like the ones that happen in museums. Two decades ago, museum researcher George Hein argued about the appropriateness of museums as constructivist learning environments [11]. However, there has been controversy ever since about the degree of guidance needed in constructivist settings, with some postulating that minimal guidance during an instructional activity is not enough to facilitate the cognitive processing necessary for learning [15]. Accumulating evidence suggests that unguided instruction during discovery learning often proves to be less effective as compared to guided instruction [19]. Since in our previous study [3] unguided students showed reduced learning gains as a result of a poorer game experience, in the current study we also evaluated the impact of facilitation during collaborative game play.

Finally, a significant aspect of learning, with great implications during social interactions, is affirmation of self [8]. 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 [25]. Different cultures nurture different values and belief systems, shaping individual self-actualization and socialization patterns (e.g., individualism vs collectivism), which, we believe, can affect collaborative game play attitudes 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 [12].

Most of the work we have reviewed is missing a rigorous evaluation approach to learning occurring through collaborative game play in museum spaces, and this is the gap we mainly aim to fill with our research. Moreover, it has not been investigated how social presence and game experience during co-located collaborative play in these spaces can be affected by culture, and the consequent impact on learning.

THEORETICAL PERSPECTIVES

In order to explore our research questions (presented below), we developed C-OLiVE (Collaborative Orchestrated Learning in Virtual Environments), a game that supports co-located collaboration of up to three players. Our work is guided by the following theoretical perspectives.

The Contextual Model of Learning

As this work involves collaborative gameplay occurring in museum spaces, it was appropriate to consider how a framework for free-choice learning can inform our instructional design and assessment. Thus, we investigated in what way the three factors of the personal context of the CML (*motivation and expectations*; *prior knowledge, interests, and beliefs*; *choice and control*) and the two factors of the sociocultural context (*within-group sociocultural mediation*; *facilitated mediation by others*) [8] can affect learning using C-OLiVE in a museum space. The personal factors imply that there are individual preferences that impact the effectiveness of the visit as far as learning is concerned, but at the same time these preferences are influenced by the social interactions between participants, which are accentuated by culture. According to Vygotsky, during these interactions prior knowledge (to some extent dependent on culture) is reviewed, revised, and transformed to new concepts in the social context, before becoming available to the individual as new knowledge [27].

Sociocultural Mediation as Orchestrated Learning

Orchestrated learning, as defined in this work, denotes the type of learning occurring as a result of coordinated actions that students need to perform in the game. Similar to how orchestra members participate in a shared community of practice where common goals and understanding are necessary for its success [17], C-OLiVE provides a (virtual) community of learners where players have to coordinate their actions and plan a common route through distributed decision-making. C-OLiVE allows players to assume more or less active roles based on their knowledge or gameplay capacity (known as *legitimate peripheral participation* [17]). Moreover, learning is facilitated through interactions with more capable peers (musicians or players) or a tutor (conductor or facilitator), which has been shown to improve individual learning benefits [27]. This aligns well with the CML, considering *sociocultural mediation by others* a considerable contributor to the learning experience [8].

C-OLIVE

The C-OLiVE game is an accurate representation of an actual steam-powered olive oil factory of the 1950s from the island of Lesvos in Greece, containing exact 3D replicas of the machinery used at the time (see Figure 1). The objective of the game is to learn about the process of olive oil production. We used a three-player setup as a means to accommodate the demands of school groups but still have a manageable group size for observation purposes.

Initially, players have to produce steam to start up the olive oil production machinery, which they then have to operate. The operation involves 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 recurring to provide ample opportunities for interaction. The players are led through the process using alerts that appear at the bottom of the map, or their own window, and have to identify and troubleshoot problems in a timely manner. Points are won or lost depending on the immediacy of troubleshooting. There are twelve different workstations (e.g., 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 some machine part (e.g., in Figure 1, *Paul* is using a wrench to help *John* attach a belt to a machine). Most such tasks are repetitive to allow a different pair of players to execute them each time. When only one player is controlling the game, an icon indicates that the task is collaborative and a second consecutive trigger executes the action.

The players interact by using wireless Xbox controllers. Free navigation in the virtual factory was designed as a means to increase the sense of agency or choice, as it has been shown to contribute to learning [2,8]. A single large front-projected non-stereoscopic display is used by all players with individual viewpoints, and also includes vital information about the game, like feedback about their actions. A more detailed description of the game design, the interface, and the tasks can be found in [3].

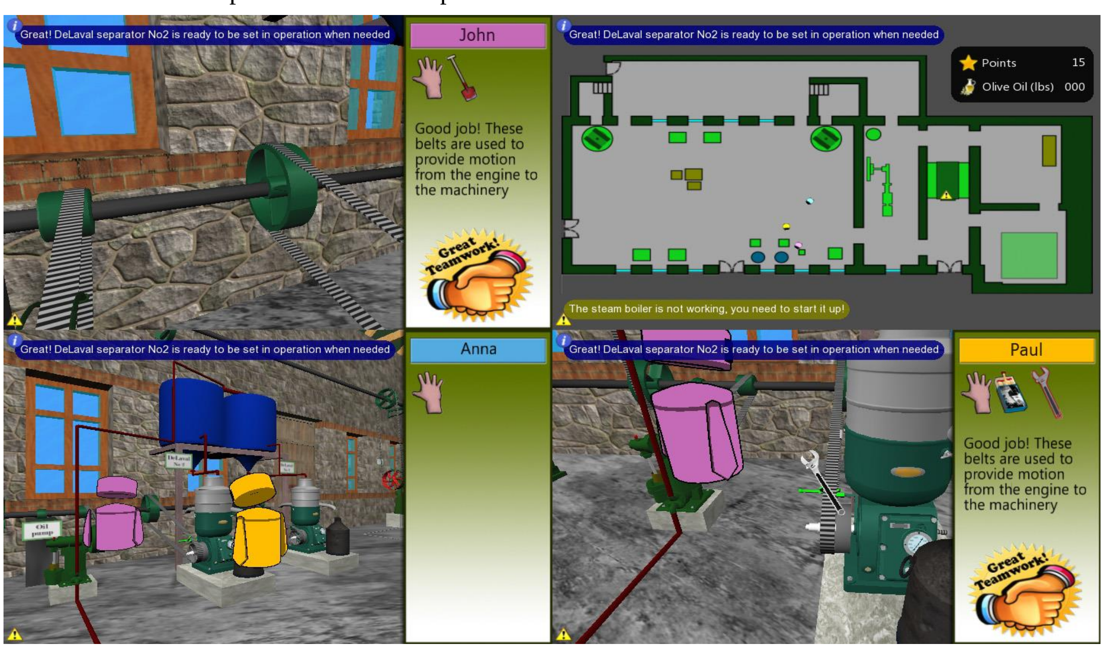

Figure 1. The interface of the C-OLiVE game for the 3-Player setup (English version shown for readability).

STUDY

The main objective of our research is to explore the potential of collaborative games as a means of fostering social interaction between young museum visitors in order to facilitate learning. Furthermore, in this second study, we wanted to investigate how attributes pertinent to a museum visit, but also affected by possible cultural and societal contingencies, might affect game experience and eventually learning. The main research questions we address are the following:

RQ1: How is learning affected by the level of interactivity students experience with a 3D game, in co-located small group informal learning settings?

RQ2: How are game experience (GE) and social presence (SP) affected by the interactivity experienced using a 3D game, in co-located small group informal learning settings?

RQ3: How do non-game elements, such as motivation for and expectations about a museum visit, interest in the domain, and perceived prior knowledge, affect engagement and learning?

RQ4: What is the role of cultural differences in mediating the effects of interactivity on learning gains?

The first two research questions relate to the goals of studying the impacts of interactivity and collaboration on learning and game experience. They are similar to the first study, with the exception of adding facilitation to our non-interactive condition, as this has been suggested to affect learning in discovery-based instruction [8,15,19]. RQ3 aims to identify other non-game elements that pertain to museum visits and are believed to influence learning, as are identified by the CML [8]. Finally, RQ4 drove our decision to choose a more ecological setting in a different culture and compare effects on learning between diverse populations, through a comparison of the two studies.

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 [3].

The main dependent variable was learning, while GE and 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[1].

Similar to our previous study, 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 [13,16], 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* [13]. The three constructs of the SPGQ are appropriate for the co-located 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 [16].

Participants

Our goal was to have a sample size of at least 111 students, based on an *a priori* power analysis (80%) for a small effect of interaction level on learning (d = 0.15). 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 boys, 71 girls). The distribution among conditions was as follows: seventeen groups (51 students) for each one of the 1P and 3P conditions and eighteen groups (54 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 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 students).

Apparatus

The game was projected on a large front-projected 16:9 wall display, and students sat at a distance of around 3 m (see Figure 2). In order to serve a larger number of groups, two workstations were set up in the museum in dedicated

[1] The study material can be accessed from: http://bit.ly/c-olive

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.

Figure 2. Experimental setup (ecological) of the 3P condition.

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.

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.

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 ($r = -0.199$, $p = 0.013$) and negative feelings ($r = -0.203$, $p = 0.011$) 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.

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 3; 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).

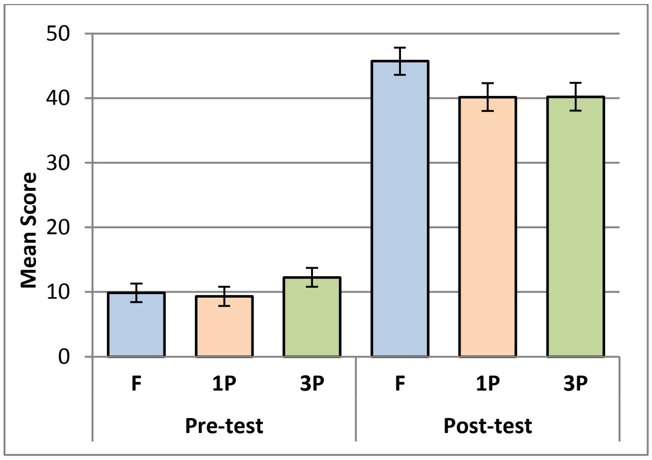

Figure 3. Effects of interaction level on learning (F=Facilitated).

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 ($p = 0.067$).

Effects of Non-Game Elements on Learning [RQ3]

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 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.

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

*significant at 5% **significant at 1%

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

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), 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.

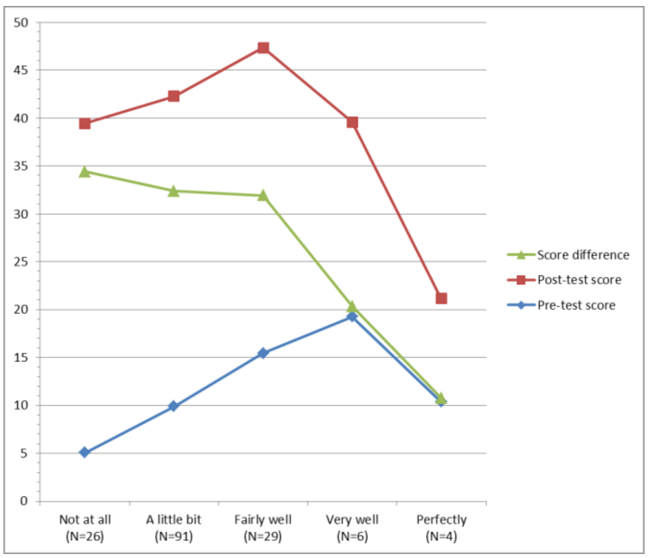

Figure 4. Test scores by perceived prior knowledge.

Comparing Studies across Cultures [RQ4]
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 5) 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 ($p = 0.001$).

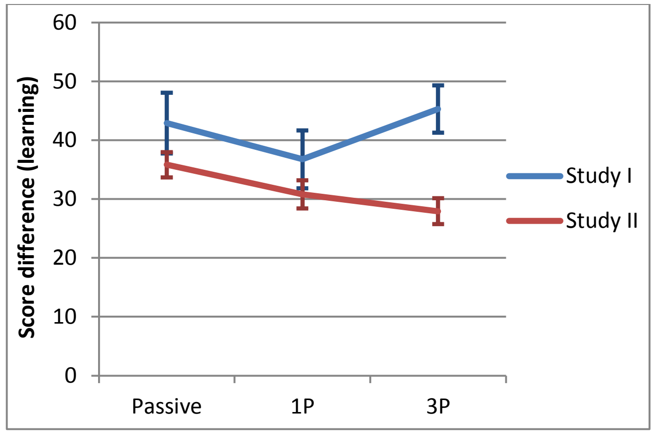

Figure 5. Effects of study x interaction level on learning.

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 $M_{dif} = 10.18$, $p = 0.022$), but this was not reflected in either the post-test nor the pre/post-test score difference.

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, children 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, children 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.

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. In responding to the factual information questions, Facilitated students scored better, and the prompts of the facilitator seemed to help them acquire 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 mostly 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 [18]. However, if challenge is far above the student's competence level, this causes anxiety [5] 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 due to 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.

Our results also show that students in the Greek 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 [24]. 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 [23]. What is important in designing instructional tools for any context is the cultural, rather than the biological, age of learners [27].

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 [21]. 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 [24].

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 [10]. Additionally, students in the museum study seemed more performance-oriented, 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 [7] might be attributed to cultural differences. We suggest that the large difference of the two cultures in the individualism dimension (IDV) of Hofstede's theory [12] explains how Greek students (IDV = 35) derived self-respect through in-group social acceptance, as compared to individual self-actualization stemming from mastery for American students (IDV = 91).

The fact that Greece is largely a collectivist culture (indicated by the low IDV score) 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. The fact that this was eventually detrimental to the game experience and learning gains was undervalued by the group.

LIMITATIONS AND FUTURE WORK

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 happening in museums (diverting from the conventional absorption-transfer model) and how this learning becomes concrete with future experiences [8]. To understand the complex learning happening outside school we need to research learning across domains and social experiences [22]. However, this study was an intermediate step to evaluate game-based, co-located 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.

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 *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.

CONCLUSION

Interactive, collaborative, game-based learning experiences for museums have been around for quite a few years, but have not been studied enough for their effectiveness, especially in different contexts and cultures. In this paper, we presented our findings from a recent study in a museum in Greece, juxtaposing the results with a controlled study in the US, reporting findings on how cultural differences might mediate the effects of interactivity on learning in these spaces. We suggest that such informal learning approaches can greatly benefit from following some key guidelines:

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.

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.

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).

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.

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 during discovery.

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 [20]. This work 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.

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