Situated Tangible Gamification of Heritage for Supporting Collaborative Learning of Young Museum Visitors

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Museums offer an ideal environment for informal cultural learning on heritage artifacts, where visitors get engaged in learning due to an intrinsic motivation. Sharing the museum space among visitors allows for collective learning experiences and socializing with each other. Museums aim to design and deploy Tangible User Interfaces (TUIs) in order to embrace the physical materialities of artifacts in the visiting experience. TUIs are believed to be more collaborative, attract more visitors, and persuade them to explore further. Cultural learning on heritage artifacts is particularly meaningful from the early age when opinions and attitudes are shaped. Museums accordingly follow a gamification approach (i.e. using game elements in a non-game context) to provide a collaborative and entertaining learning experience to young visitors. In this study, we investigate the implications of merging these two approaches in order to take advantage of the qualities of both TUIs and gamification in an educational museum context.

Accordingly, we present *TouchTomb* and its evaluation in a real-world museum environment. *TouchTomb* is a *situated tangible gamification* installation that aims to enhance informal cultural learning for young visitors and to foster engagement and collaboration among them. The basis of the installation is a shared progress bar and three games with different spatial configurations, embedded into a custom fabricated replica of an original ancient Egyptian tomb-chapel wall on a 1:1 scale. Our field study involved 14 school visits with a total number of 190 school pupils (from 10 to 14 years old). We deployed a mixed-method evaluation to investigate how such a tangible gamification approach entertains and educates 15 pupils collectively for a maximum of 15 minutes, including the evaluation procedures. We particularly investigated how the different spatial configurations of the game setups influenced the stages of pupils' cultural learning, and the levels of engagement and collaboration among them. We conclude the paper by discussing the qualities of tangible gamification and its role in facilitating cultural learning. For instance, cultural learning is enhanced by situating heritage artifacts in the experience, and embedding

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learning in the reward system. Engagement and collaboration among visitors are fostered by creating a sense of ownership and designing a diversity of goals.

• Human-centered computing→Human computer interaction (HCI), **Human-centered computing→Interaction design**, and **• Applied computing→Arts and humanities.**

General Terms: gamification, tangible interaction, built heritage.

Additional Key Words and Phrases: tangible interaction; gamification; tangible gamification; cultural learning; collaboration; heritage communication; museum studies; human-computer interaction.

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1. INTRODUCTION

The educational role of museums is crucial to communicate the vast amounts of artifacts' information to the general public [Hooper-Greenhill, 2013]. Museums are expected to broaden the general knowledge of their visitors during their visiting experience [Falk, 1998; Kelly, 2007]. Heritage museums therefore offer an ideal environment for informal cultural learning [Hein, 1998; Hooper-Greenhill, 1999; Falk and Dierking, 2002]. Cultural learning is described as the use of communication mediums for the acquisition of knowledge that encourages cultural awareness and appreciation [Ibrahim et al, 2015]. From related literature [Dierking and Falk, 1998; Ham, 2013], people who learn about cultural heritage are either obliged to learn due to educational requirements, or people who choose to learn for fun, or get engaged in learning due to an internal motivation. The latter denotes to 'informal cultural learning', where people are driven to pay attention and learn due to intrinsic motivation related to what they are hearing, seeing, reading, or doing [Ibrahim et al, 2015]. Museums offer a collective learning experience by sharing the space among visitors and socializing with each other depending on mutual interests [Simon, 2010]. It is widely admitted that establishing social relationships during informal learning processes is among the main expectations of museum visitors [Vermeeren et al, 2018].

Museum environments bring people into contact with original physical artifacts in a real scale and texture, enjoying their visible history. Heritage museum artifacts are rich in content and encompass several aspects of tacit knowledge which are relatively challenging to communicate due to their implicit character, such as architectural qualities, historical values and artistic features [Nofal et al, 2018]. Museums accordingly aim to design and deploy Tangible User Interfaces (TUIs) in order to embrace the physical materialities of artifacts in the visiting experience [Dudley, 2010]. TUIs are believed to be more collaborative, attract more visitors, and persuade them to explore further. The qualities of TUIs might well facilitate heritage communication in museums, such as requiring little experience or skills, performing better in terms of recalling information because it requires multimodal ways of human perception to discover and decipher their meaning [Seo et al, 2015], supporting collaborative and participative processes among users [Claes and Vande Moere, 2015; Not et al, 2019], and attracting more visitors towards more extensive forms of exploration during interactive exhibits [Ma et al, 2015].

Cultural learning on heritage artifacts is particularly meaningful from the early age when opinions and attitudes are shaped. Educating youngsters about heritage is challenging when linked to educational programs in schools due to lack of interest and protection issues. Young visitors constitute a significant part of museum visitorship, whose experience is considered as a powerful mediator of

memory, enjoyment, and learning [Piscitelli and Anderson, 2001]. Young visitors gain understanding from their observations of, participation in, and reflection of a variety of social activities that derive from their physical interactions with museum artifacts [Henderson and Atencio, 2007]. For them, learning is intrinsically motivating when it is spontaneous. They are motivated to learn when they are involved in meaningful activities and experiential processes, meaning that their experience might well involve sensory and emotional faculties beside intellectual capabilities [Csikszentmihalyi and Hemanson, 1995]. Yet, museums face a challenge of offering a 'situated' environment by integrating various situations for learning into lifelong opportunities that reinforce each other [Paris, 1997]. These situations can be effective if they promote the motivational processes embodied in constructing personal meaning, making choices about goals and engagement, adjusting challenges, taking responsibility and control for self-directed learning, and collaborating for joint goals and teamwork.

According to the theories of cognitive development, young children benefit from learning that is organized as an interaction among peers 'collaborative learning' [Crook, 1998], which is believed to improve both learning outcomes and engagement [Nastasi and Clements, 1992]. Collaboration allows for co-constructions within collaborative problem solving, and enables children to articulate their thoughts publicly [Hoyles, 1985], which helps in bringing to consciousness their ideas that they are just beginning to grasp intuitively. Therefore, the gamification approach, which denotes to the application of typical game elements in non-game context, seems to be a promising solution in heritage museums for providing a collaborative and entertaining learning experience to young visitors. Although gamification aims to maximize enjoyment and engagement through capturing children' interest, inspiring them to continue learning in their contexts [Huang and Soman, 2013], most heritage game interfaces are technological in nature, and are not directly connected to the heritage context or content. For instance, gamification supports the learning of heritage through different techniques, such as serious games that can be played online [Froschauer et al, 2012] or running as a gamified smartphone application during the museum visit [Coenen et al, 2013], or even by combining gamification with augmented reality [Hammady et al, 2016].

Consequently, we introduce the approach of *situated tangible gamification* by embedding game setups with different spatial configurations into a TUI in order to enhance informal cultural learning and to foster collaboration and engagement of museum visitors. Through a field study in a real-world museum environment, we deployed a mixed-method evaluation to investigate how such a tangible gamification approach enhances the cultural learning of young museum visitors (10-14 years old) on an ancient Egyptian tomb-chapel exhibited in scale 1:1 at the Royal Museums of Art and History in Brussels. We particularly investigated how the different spatial configurations of the game setups influenced the stages of pupils' cultural learning, and the levels of engagement and collaboration among them. In particular, the following research questions are explored: (a) how do the spatial configurations of tangible gamification impact cultural learning of young museum visitors; and (b) how does the diversification of tasks augment social interaction and collaboration among them?

2. RELATED WORK

2.1 Tangible User Interfaces (TUIs)

The research of tangible interaction tends to investigate how computational and mechanical advancements can be combined to allow novel forms of natural manipulation and full-body interaction with data and information [Hornecker, 2005]. In comparison to graphical user interfaces (GUIs), tangible user interfaces (TUIs) are believed to be relatively more intuitive, as TUIs tend to communicate meaning through their physical affordances [Macaranas et al, 2012], such as by mapping information into physical shapes and forms, or into its material attributes (e.g., size, shape, texture, color, weight). Further, the embedded representation of information by giving the data

physical form and blending it with physical environment is believed to be the most useful at human-accessible scales, where the physical size and distribution of the referents maximizes visibility and reachability [Willett et al, 2017].

TUIs applications in museums vary in terms of how the interface is situated in the context of the artifact; from less situated interaction when the original artifact is not exhibited at the museum [Nofal et al, 2018] or the interface and the artifact are located in distant places in the museum for provoking visitors' curiosity [Duranti, 2017], to a semi-situated experience, such as using a smartphone connected to a physical magnifying lens to examine museum artifacts and receive extra digital content on the smartphone [Van der Vaart and Damala, 2015], to more situated experience by using the original artifact as an interaction device [Not et al, 2019]. Accordingly, TUIs offer a spectrum of opportunities for museums with regard to the level of situatedness, and targeting specific audiences to communicate tangible and intangible heritage information. Further, the tactile qualities of tangible interaction allow for interactive installations in museums that target specific audience [Duranti, 2017]. For instance, the mix of materialities encourages creativity for children's playful exploration in museums [Taylor et al, 2015].

In general, the qualities of TUIs are used to promote learning activities, such as the use of physical materials to facilitate linking between perception and cognition [Marshall, 2007]. Likewise, three-dimensional forms are easier to be perceived through haptic rendering representations than through visual displays alone [Gillet et al, 2005]. The interlinks between physical actions and digital outcomes of TUIs might be particularly suitable for engaging children in playful learning [Price et al, 2003], while increasing the size of the TUI creates a shared space among users, allowing for collaborative learning [Suzuki and Kato, 1995].

2.2 Gamification to Support Learning

Educational games are believed to balance between entertainment and didactic objectives. There is a conceptual separation between the ideas of game and play. Games are seen as rule-bound, goal-oriented and finite, whereas 'play' implies freedom of choice and unbound exploration. *Gamification* is used to refer to the use of game design elements in non-game contexts [Deterding et al, 2011]. These game design elements include interface design patterns, such as the use of badges and leaderboards; gaming mechanics such as the use of time constraints and limiting resources; as well as more broadly, game design principles such as having to complete clear goals and receiving rewards.

To design a *gamified* experience, possibly in a heritage context, one needs to take into consideration a myriad of factors. A gamified interaction typically gives rewards and punishments as well as adds quantifiable constraints (i.e. time) while performing tasks thus creating artificial conflicts and consequently driving the players through a designed experience. Similar principles of gamified interaction also apply even for puzzle-like or collaborative games. In those cases the referred *conflict* simply gets transferred into a conflict between the player and the game rather than between players [Salen and Zimmerman, 2004]. Rewards for gamification are both immediate, i.e. receiving a coin for defeating an enemy in an adventure game (immediate goal) but are also overarching: the final quest that is only achieved by completing a series of intermediate goals. For instance, in a treasure hunt game design, with an overarching goal of exploring a full archaeological area, a series of 3D reconstructions of buildings are awarded to the participants as they achieve the intermediate goals of properly locating them [Sun et al, 2008].

When referring to education, the outcomes of a game need to be evaluated based on learning criteria. Though gamification is often employed in the education of children for its motivational affordances [Huotari and Hamari, 2012]. There has been critique for the imbalance of actual learning material and distractions from the non-educational, gamified elements [Andrade et al., 2016]. This

balance however is not clear-cut. When compared with traditional (i.e. non-gamified) learning methods in respect to time to achieve progressive learning goals, the gamified approach starts with lower effectiveness (due to the need to adapt to the game itself) but then manages to retain the continuous engagement as time progresses and the learning goals evolve [Kim and Lee, 2015]. Gamification is also evaluated in its ability to inspire intrinsic instructional activities to children, namely learning when there is no external pressure from adults [Carvalho et al, 2015]. Gamification techniques have been used to bypass the perceived overall difficulty of tasks by gradually solving easier sub-tasks [Kim et al, 2018] and therefore maintaining the balance between challenge and skill. This provides a bridge between experiential learning theory [Kolb, 1984] and gaming, through the concept of learner or player 'flow' to describe a state in which a person has a good balance between skill and challenge [Kiili, 2005].

Gamified experiences do not need to be complete games but can contain only game elements. In heritage communication, informal cultural learning can be gamified in types such as: observation tasks; which stimulate spatial reasoning and contextualized search as in identifying parts of a painting, reflection tasks; which aim for synthesis of clues and past information through quizzes and arcade tasks; which stimulate fantasy as in ancient world simulation games [Bellotti, 2012]. The use of gamification in existing literature generally enhances learning [Hamari et al, 2014] and when referring to collaborative learning in particular, games have been identified for supporting exploration and helping to overcome group social conformity [Kim et al, 2018]. Nevertheless, there has also been criticism for its side-effects in collaborative contexts, such as the emergence of unwanted competition [Hamari et al, 2014].

3. DESIGN AND DEVELOPMENT

In order to enable informal cultural learning for young museum visitors, and to investigate the influence of tangible gamification on their learning, we aim for a physical, immersive experience with real-life, human-scale artifacts of high cultural and historical value. In this section, we discuss the choice of the context and explain our design.

3.1 Context

Most ancient Egyptian monuments are characterized by tacit knowledge like historical values as well as distinctive architectural qualities, which all are challenging to be conveyed to public visitors. We chose to communicate the tacit heritage knowledge of the *Tomb-chapel of Neferirtenef* (Figure 1.a and Figure 1.b) specifically because: (a) the original tomb is exhibited in scale 1:1 at the antiquity department at the Royal Museum of Art and History in Brussels; (b) its features are comprised of a rich variety of knowledge that could be communicated to visitors, and accordingly (c) it is valorized in learning plans for school visits, as the history of Egypt is part of their educational curriculum. As such, our study was deployed in close collaboration with the Antiquity Department of the Royal Museum of Art and History in Brussels. The museum possesses the largest collection of Egyptian antiquities in Belgium.

The tomb-chapel originates from the Memphite necropolis, in Saqqara and dates to the early 5th Dynasty (ca. 2494-2455 BC). It originally stood near the southeast corner of the funerary complex of pharaoh Djoser (3rd Dynasty, ca. 2667-2648 BC) in Saqqara. The monument is the largest ancient Egyptian work of art in Belgium, acquired in 1906 by curator Jean Capart. He had accepted the offer of Gaston Maspero, then director of the Department of Antiquities in Egypt, who hoped to counter the pillaging of the tombs in the Saqqara necropolis by offering the major museums around the world the opportunity to acquire an entire monument for their collection [Van de Walle, 1978]. Ever since it was

installed in the Brussels museum in 1907, the funerary chapel of Neferirtenef has been one of the most iconic works of art in the Egyptian galleries.

The chapel is part of a mastaba complex, a tomb for the elite consisting of a rectangular structure above ground and an underground burial chamber accessible via a vertical shaft. Offerings for the deceased could be placed in the tomb-chapel, which is part of the above-ground building [Van de Walle, 1978]. Neferirtenef's name is repeatedly mentioned on the walls and he is represented graphically, together with his family, on the wall reliefs that also show offerings and goods being brought by retainers. The west wall includes two false doors (Figure 1.b), essential features in Egyptian tombs: these are stone doors through which the spirit of the deceased could pass, in order to receive the sustenance offered to him by relatives in the chapel.

(a) *(b)* *(c)*

Figure 1: Tomb-chapel of *Neferirtenef*: (a) the exterior of the tomb-chapel as installed at the Royal Museums of Art and History in Brussels, (b) the interior West wall of the chapel, and (c) the selected part of the wall relief that contains different types of tacit knowledge.

The tomb-chapel is encapsulated in a monotonous cube structure (Figure 1.a) at the museum which somehow is withdrawn from museum visitors. From inside, the value of the architectural features and the abundance of reliefs remain unclear and obscured for lay visitors. Consequently, we organized a 2-hour co-design workshop with 3 heritage professionals (2 males, 1 female), consisting of one museum curator and two academic researchers in Egyptology. The workshop was conducted to define: (a) what specific information the museum wishes to communicate to visitors; (b) what kind of visitors are more interested in the Egyptian collection, and the tomb-chapel in particular; and (c) what kind of installations that can be used in the museum context. We found that young visitors (10-14 years old) are the most visiting category to this tomb-chapel due to the direct link to their educational curriculum. They come in groups as guided school visits, having limited time to visit the entire Egyptian galleries. The workshop concluded by selecting a specific section of the internal west wall of the tomb-chapel (Figure 1.c) because its decorations contain a variation of distinct types of tacit knowledge of Egyptian built heritage:

- *Architectural qualities*. The tomb-chapel has one real door and two false-doors. The false-door is considered a threshold between the worlds of the living and the dead, their spirit can enter or leave the grave. A rolled-up reed mat is hanging above a doorway (both real and false doors), which is very recognizable in ancient Egyptian architecture; it is symbolically in stone in the tomb-chapel.
- *Historical values*. In ancient Egypt it was customary to bring different types of offerings to the deceased in the tomb-chapels. Drawings on the wall represent these offerings, as if the deceased would be able to receive them forever.

- *Artistic features*. Like in any ancient Egyptian art, men were painted in reddish brown because they were exposed to the sun due to their outdoor activities, while women were painted in yellow beige because they were responsible for indoor activities. Thus, gender could be determined at a single glance.

3.2 Conceptual Design

We present *TouchTomb*, a tangible gamified installation that facilitates the communication of tacit knowledge of the Neferirtenef tomb-chapel in an informal cultural learning setup. As part of our design requirements, the installation needs to be affordable, robust, easy to replace, and most importantly to engage one guided school visit, which consists of approximately 15 pupils that are between 10 and 14 years old, for a maximum of 15 minutes. To allow for the appropriate evaluation methods to be subsequently deployed, these constraints mean that an extreme short time span is dedicated to the actual engagement with the installation.

We built a physical, life-sized replica wall of the chosen section of the interior west wall of the tomb-chapel as an interactive, tangible interface. The wall was deliberately positioned just outside the original tomb-chapel as shown in Figure 2.a. The wall hosted three distinct game setups. Each game setup was specifically designed to communicate a specific type of the abovementioned tacit heritage information: architectural, historical, and artistic (as explained in Section 3.1). While each of the games consisted of reaching a specific goal, their progress was explicitly shared with the pupils of all the games by way of a common progress bar. The strategy of separating pupils into three collaborative groups that compete in parallel enabled smaller group sizes and different spatial configurations of the game setups.

Each game setup was introduced by a question plate that was located in the middle of the wall with a distinct color for each game setup. A light-emitting bar graph conveyed the progression of solving each of the games. Each game was based on two distinct reward systems. When completing an intermediate goal a partial reward was given by adding a light to the progress bar. Once the progress bar was fully-lit, meaning all intermediate goals are completed, a grand reward was given to denote the end of the game. In practice, this means revealing extra information corresponds to the game setup by rotating the question plate 180° (Figure 2.c). As the back of the question plate contained textual information that explained the answer of each of the questions.

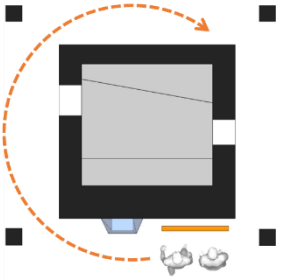
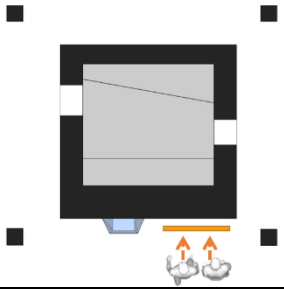
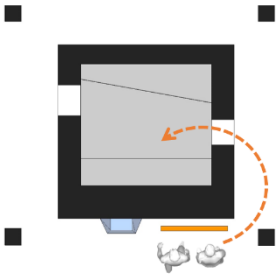
(a) *(b)* *(c)*

Figure 2: *TouchTomb*: a replica wall in scale 1:1 of the chosen section of the interior west wall of the tomb-chapel: (a) its location outside the tomb-chapel, (b) a close-up view of the installation, showing the three games, and (c) rotating the question plate to reveal extra information when the game is solved.

3.3 Game Setups

The three game setups (Figure 2.b) are coined as: *'around' exploration*, *'in front' interaction* and *'inside' navigation*, as they were purposefully designed around three different spatial configurations to investigate how these configurations impact interaction with tangible and real-life interface, as shown in Table 1. In the *'around' exploration* setup, visitors are expected to solve a 3D puzzle and to explore where it fits in the tomb-chapel. The semi-situated interface of the *'in front' interaction* setup, consisted of the replica wall of the tomb-chapel that provides visitors with familiar physical objects and actions. The *'inside' navigation* setup embraced a fully situated interface that required a direct interaction with the original tomb-chapel, which becomes the output medium as the interface becomes embodied by the physical shape and materiality of the artifact itself.

Table 1: Comparison between the three game setups of *TouchTomb*.

	'around' exploration	*'in front' interaction*	*'inside' navigation*
Game setup	Exploring the tomb all around to solve the game. 	Interacting only in front of the wall for solving the game. 	Navigating inside the tomb to find hints for solving the game. 
Challenge	Solving 3D puzzle that represent the rolled-up reed mat at the top of the false door. 	Sorting magnetic cards for the different types of offerings in ancient Egypt. 	Mapping coloured cards to the human figures according to the corresponding painted colours. 
Final reward: cultural learning	*Architectural qualities:* Learning about the false-door in the ancient Egyptian architecture. 	*Historical values:* Learning the different types of offering in ancient Egypt. 	*Artistic features:* Learning the role of color in the ancient Egyptian art. 

3.3.1 'around' exploration

The *'around'* game setup urges visitors to solve 12 pieces of a 3D puzzle on a custom-designed platform located on a table beside the tomb-chapel, to locate the result on *TouchTomb* where they think the result belongs, and to find another example of the puzzle result, and thus they are stimulated to explore the monument all-around.

We chose the semi-cylindrical top of the false door as the puzzle detail, which represents, in stone, a rolled-up reed mat. As a constraint, the puzzle has to be solved on a custom-designed platform. When all pieces are in place, a LED strip lights up around the puzzle pieces as a reward (Figure 3.a). Then, by exploring the tomb-chapel, visitors were expected to discover that the location of the rolled-up reed mat above the false door as well as above the real door, thus by analogy the closed, false door was also considered as a passageway (for the soul of the dead). Further, when the platform is hung on the replica wall, the 12 LEDs on the progress bar of the first game light up, revealing extra information on rolled-up reed mat of the false-door.

3.3.2 'in front' interaction

The *'in front'* game setup stimulates visitors to stand in front of *TouchTomb* in order to search and map 12 offering cards to the corresponding craved onto the replica wall. Each card has a specific icon of one of the main offering types in ancient Egypt (Figure 3.b). In total there were 4 meat, 4 bread and 4 fruit cards. Visitors were expected to sort the cards by placing them to the corresponding drawings on the replica wall. One LED lights up in the progress bar for each valid placement. When all cards are correctly placed, extra information is revealed to inform them that those drawings on the wall represent offerings in ancient Egypt, namely that the deceased would be able to receive them forever.

3.3.3 'inside' navigation

The *'inside'* game setup requires visitors to go inside the original tomb-chapel to examine which human figure is painted in which color. Visitors are given 12 gender cards, each card has a specific color for the painted human figures on the original wall (Figure 3.c). In total they were given 5 yellow beige and 7 reddish brown human figures. They were expected to place the cards on the corresponding human figure on the replica wall according to their colors. Similar to the previous setup, one LED lights up in the progress bar for each valid placement. When all cards are correctly placed, extra information is revealed to explain the role of color in ancient Egyptian art and how easy the gender could be determined at a single glance.

3.4 Technical Development

TouchTomb was fabricated to simulate the original wall of the tomb-chapel within obvious constraints of financial costs and robustness. The overall dimensions are 180 cm width and 240 cm height, comprising 5 panels of MDF wood that are attached together with metal supporters. In the middle of the wall (i.e. false-door). The progress bar consisted of a LED strip, and connected to an Arduino Mega in the backside of *TouchTomb* to control six Servo motors for rotating the three plates of questions (i.e. two motors for each), as shown in Figure 2.c.

In the *'around'* game setup, we replicated in scale 1:1 the reed mat by 3D printing 12 jigsaw puzzle pieces in a semi-translucent white polymer, the prominent pieces were then colored in gold to stand out (Figure 3.a). The custom-designed platform has an Arduino Mega integrated with 12 LDR light sensors to detect each of the puzzle pieces and to illuminate the LED strip. All puzzle pieces have an integrated magnet to stick to the platform, and the platform has four strong magnets from the backside, so that it could be hung vertically to the *TouchTomb* in its corresponding location. For both the offering cards of *'in front'* game and gender cards of *'inside'* game, each card has 3 magnets from

the back side with an integrated electronic circuit that is consistent for each offering category (Figure 3.b), and for each gender category (Figure 3.c). Cards were not unique, meaning that for example any fruit card in *'in front'* game fits with any fruit-drawing, and any dark card in *'inside'* game fits with any man-figure on the wall. For the sake of physical affordance, we engraved the outlines of all cards to be aligned on *TouchTomb*, we also considered the issues of cost and ease of replacement by producing more spare cards.

Since the original tomb-chapel is exhibited in a national museum, all object labels and gallery texts needed to be presented in the two main official languages (i.e. French and Dutch). Accordingly, we custom designed the interface of *TouchTomb* to support as many languages as needed, by allowing the explanatory plates to be easily removable and exchangeable by means of magnetic attachments (Figure 3.d).

(a) *(b)* *(c)* *(d)*

Figure 3: Technical installation: (a) puzzle pieces with integrated magnets, wiring inside the platform of sensors and LED strip, custom-designed platform with the 12 light sensors, and the LED lights up when all pieces are correctly placed, (b) offering cards: front sides, wiring from inside, and magnets on the back side, (c) gender cards: front sides, wiring from inside, and magnets on the back side, and (d) the multi-language interface by changing one of the magnetic plates from 'Dutch' to 'French' according to the participating group.

4. METHODOLOGY

4.1 Evaluation Methods

The evaluation study deployed a mixed-method methodology. A complete list of the scheduled school visits for Egypt galleries for the months of October and November 2018 was provided by the museum. Then, we asked the public service of the museum to recruit certain school visits based on their age category, mother tongue language, and time of visit. After giving a short-guided tour to each school visit about the general historical background of the tomb-chapel, we commenced the experiment with briefing the pupils about how they were expected to interact with *TouchTomb*. We asked teachers or guides to divide the pupils into three equal groups. Each group was assigned to a game setup, thus ensuring that each visit took part in all three setups mentioned above. The evaluation consisted of observing all interactions with *TouchTomb* and each other, a short semi-structured interview that focused on cultural learning, and a collaborative user experience questionnaire that captured the overall experience of the pupils. We obtained a permission to conduct the study (Key G-2018 04 1213) from the Ethical Commission of KU Leuven.

4.1.1 Observation

All pupils' interactions were observed and video-recorded, and then manually listed and analyzed in an Excel spreadsheet. The causal aspects of situatedness where captured by observing whether, when and which groups went inside the original tomb-chapel, and how this steered their game-solving

and according learning activities. We manually noted all relevant collaborative and social interactions among groups, such as via talking (e.g. reviewing or guiding each other), or via actions (e.g. solving together or dividing the tasks among themselves). Further, we combined the durations of each game together with the human behaviors to determine the overall usability, such as whether the pupils easily understood the game rules and whether they paid attention to the progress bar.

4.1.2 Interviews

Both pupils and teachers were invited to partake in a concise structured interview that was audio-recorded. After the experimental phase of the study, we invited pupils of the three teams to partake in three structured and audio-recorded group interviews. Concretely, pupils were tested whether they acquired the intended cultural learning (Table 1) by way of open-ended questions: (a) in the *'around'* game, pupils were asked about the meaning of the false-door in the ancient Egyptian architecture, what is hanging above it, and whether there were similar places around or in the tomb-chapel; in (b) the *'in front'* game, about the main categories of offering in ancient Egypt, and what those offerings mean; and in (c) *'inside'* game about the colors of human figures in Egyptian paintings, and what those colors meant. The interviews polled about the pupils' appreciation of the experience and whether they preferred to try it alone, with family, or with school. Although teachers did not interact with the installation, they form a major stakeholder in reaching the learning objectives and in acting as a critical witness from a third-person perspective. Accordingly, we invited teachers to a concise semi-structured interview, which focused on their impression and appreciation for these kinds of installations, in an attempt to open up their critical view towards more subjective answers and suggestions.

4.1.3 User experience questionnaire

The interviews were followed by a novel user-experience questionnaire (UEQ) that measured in a collaborative and engaging manner how the experience of the pupils was enjoyable, easy, clear, attractive, creative, and informative. The questionnaire was designed as a tangible extension of the game experience by using physical game objects (i.e. LEGO® blocks) that could be placed on a 5-point Likert scale, from -2 (representing the most negative answer) to +2 (representing the most positive answer), with 0 as the neutral answer. The three used colors of the blocks corresponded each to a unique game setup (i.e. yellow for *'around'*, red for *'in front'*, and blue for *'inside'*). Each pupil was handed six blocks in the corresponding color to answer the six questions in the questionnaire (Figure 4.b). The language of the questionnaire could be easily switched by replacing an underlying sheet of paper, as shown in Figure 4.a.

(a) *(b)*

Figure 4: A tangible gamified user-experience questionnaire using LEGO® blocks: (a) the custom designed questionnaire, and (b) a group of pupils collaboratively evaluating their experience (i.e. yellow for *'around'* game, red for *'in front'* game, and blue for *'inside'* game).

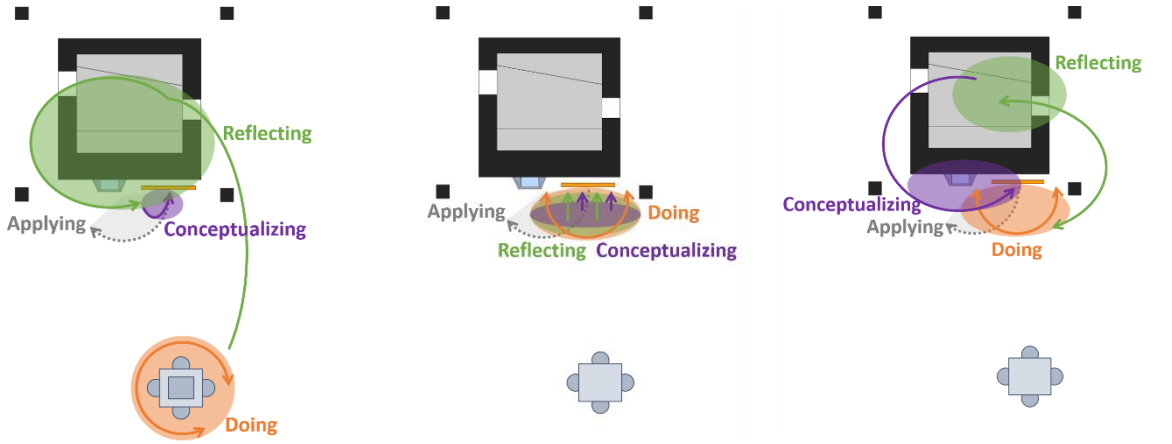
5. RESULTS

The study involved 14 school visits with a total number of 190 school pupils, both Dutch and French speaking from all over Belgium. We categorized our results into two sections: (a) how the three spatial configurations of *TouchTomb* impacted the stages of pupils' cultural learning about architectural, historical and artistic information of the tomb-chapel; (b) how pupils appreciated the overall user experience, and how the design of a tangible game in a scale 1:1 encourages them to collaborate, spatially as well as socially.

5.1 Situated Cultural Learning

Our results on cultural learning are adapted from Kolb's model of experiential learning [Kolb, 1984]. This model has been increasingly popular in museum interpretation and education programs [Sitzia, 2016], as it frames the process of knowledge creation through the transformation of experience, starting from how pupils have a concrete experience (doing), followed by a reflective observation (reflecting) and an abstract conceptualization (conceptualizing), and ending with the active experimentation of the knowledge they gained (applying) by empirical testing the implications of the seen concepts. Accordingly, the three game setups distributed the learning cycle of young visitors in terms of how they occurred in space (Figure 5) and time (Figure 6) in significantly differing ways.

In general, the learning stages of the *'around'* game setup were spatially dispersed between the table to the tomb-chapel passing by the replica wall, and temporally sequential with several gaps in-between. While, the learning stages were more clustered in the *'in front'* game setup in both space and time, occurring in front of the replica wall and overlapping in time. In the *'inside'* game setup the learning stages were spatially contained in front of the replica wall and inside the tomb-chapel, and temporally intermittent, meaning that learning stages were not always continuous.



(a) *(b)* *(c)*

Figure 5: Spatial distribution of the four learning stages for the three game setups: (a) dispersed in the *'around'* game setup, (b) clustered in the *'in front'* game setup, and (c) contained in the *'inside'* game setup.

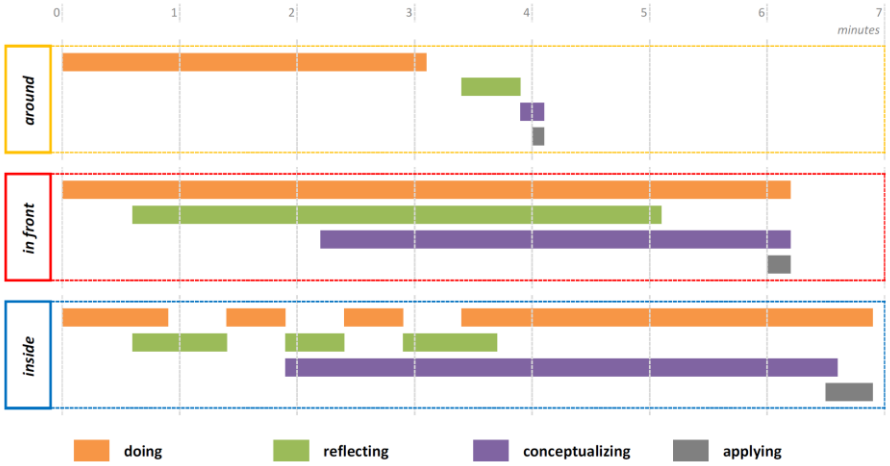


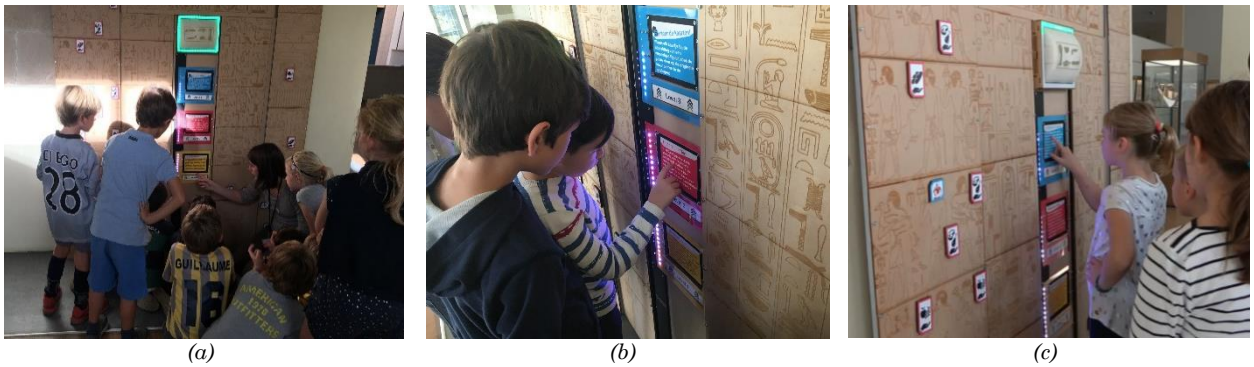
Figure 6: Timeline of the three game setups showing the average time duration of each learning stage by the 14 school visits: (a) sequential in *'around'*, (b) clustered in *'in front'*, and (c) intermittent in *'inside'*.

In the *'around'* setup, learning stages were affected by the spatially dispersed tasks between the table to the tomb-chapel passing by the replica wall. All groups started with the 'doing' stage by solving the puzzle on a table that was relatively far from the context (Figure 5.a), where they considered it only as a game with no link to the context (i.e. tomb-chapel). The implied physical and scale relationship was not obvious, which made them asking what to do after solving the puzzle, although they all read the question on the interface. After a time lag, they went inside the tomb-chapel to compare their solved puzzle to the inscriptions on the wall 'reflecting'. Subsequently, they managed to place the solved puzzle above the false-door on the replica wall 'conceptualizing'. Although almost all groups (N=13) managed to answer the question of the meaning of the false-door in the ancient Egyptian architecture *"dead people can go through this door to the second life"* (participant 9), only half of the groups (N=7) knew that the piece above the door (i.e. result of the puzzle) represents the name of the tomb-owner in hieroglyphs. That might well be the result of the crowdedness and thus not watching the revealed information after placing the puzzle on the replica wall, or because of the ergonomics issue that the plate of the question is very low in relation to the puzzle spot. For each group, we had to explicitly ask pupils to look at the flipped question plate (i.e. the grand reward), or the teacher had to explain the information to the entire group (Figure 7.a). Almost none of them were able to mention the rolled-up reed mat above the real entrance of the tomb, but only few of them (N=3) mentioned the second false door inside.

In contrast, the learning stages of *'in front'* setup were more clustered and occurred only in front of the replica wall with several time overlaps (Figure 5.b). Pupils started to place their first offering cards on the wall in a meaningless pattern 'doing', just to check if there is a LED lights up in the progress bar. Since pupils kept an eye on the progress bar to make sure whether their answer was right or not, they started to 'reflect' on the icons on cards and link them to the drawings on the wall; *"this is not fruit, we should place a meat card*" (participant 4). The stage of 'conceptualizing' occurred when they associate the question about offerings to the actions they were doing. While the stage of 'applying' came after solving the game and the offerings' information is revealed to them, as several groups were asked by teachers to read out loudly the revealed information to the colleagues (Figure 7.b). Time correlation between the learning stages influenced how pupils answered the learning questions in the interview. All groups (N=14) managed to answer the question of mentioning the main categories of offering in ancient Egypt. Many of them (N=9) were able to answer the second part of the question (i.e. the meaning of the offering) using their own words *"gifts to the dead people to have a*

good life in the other world" (Participant 13). The remaining groups either they did not answer that part or they answered it wrongly based on their imagination *"vitamins for ancient Egyptians"* (participant 15), meaning that they less cared about the textual information.

The learning stages of *'inside'* setup were contained and achieved in multiple spatial zones, and temporally intermittent, meaning that learning stages were not always continuous (Figure 5.c). Pupils started with placing the gender cards on the wall without understanding what they mean 'doing'. Reading the question carefully, they realized that they have to go inside the tomb and look at the original wall, thus they recognize that colors on cards mean figures' colors on the wall 'reflecting'. By going forth and back from the replica wall to the original wall inside and by keeping an eye on the progress bar, they understood that dark colors mean men and light colors mean women 'conceptualizing'; one pupil was shouting to her colleague *"I found a man here, give me a man card"* instead of *"a dark card"* (participant 3). After solving the game and more information is revealed to pupils on the paintings in ancient Egypt 'applying', they seemed to have an intrinsic motivation to read the information that has been revealed (Figure 7.c). In this setup, the learning stages were contextually and timely interrelated, which positively affected the learning of pupils. All groups (N=14) managed to answer the question of the meaning of color in the Egyptian paintings. The majority of them (N=11) were even able to answer the 'Why' part of the question by recognizing that a dark color corresponds to men because they were exposed to the sun due to their outdoor activities, while a light color represents women because they were responsible for indoor activities.



(a) *(b)* *(c)*

Figure 7: The grand reward of the game represents the 'applying' learning stage for the participants (a) a guide explains the revealed information to the entire group after solving the *'around'* game, (b) a participant from *'in front'* game is asked by the teacher to read out loudly the revealed information to his colleagues, and (c) a participant from *'inside'* game read out loud the information that has been revealed after solving the game.

In general, participants of *'inside'* and *'in front'* games found the experience very informative (69% and 67% respectively) compared to the pupils' answers of *'around'* game (52%), as illustrated in Figure 8. We assume that *'around'* game might well be less informative because of (a) the decontextualized setup of this game, as the table was not directly connected to the tomb, (b) the final reward of this game was not easily visible to pupils due to crowdedness and ergonomics, and (c) the information content might be a bit harder to convey, unlike the familiar types of offerings (i.e. *'in front'* game) and the colors of paintings (i.e. *'inside'* game).

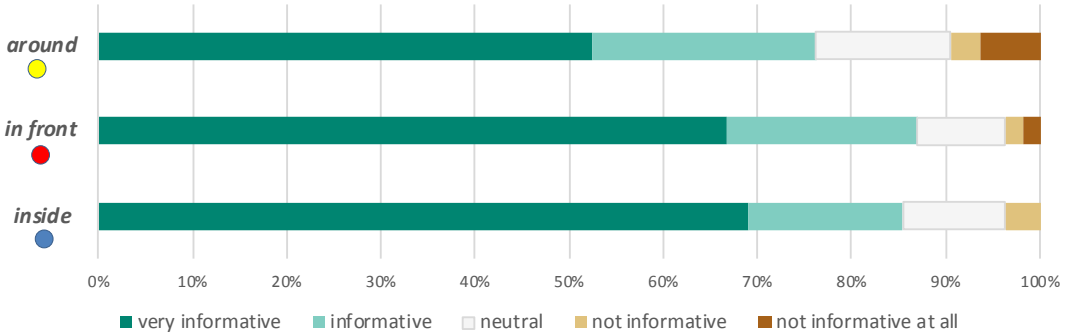


Figure 8: Pupils' answers on the tangible user experience questionnaire for the three game setups on how informative their experience was.

5.2 User Experience

In this section, we report on the user experience in terms of their types of collaboration and social interaction, their forms of engagement and appreciation, the impact of game elements on their experience, and their replies on the user experience questionnaire.

5.2.1 Collaboration and social interaction

All participants stated that they prefer not to have this experience individually but in groups: 75 % with school-mates, and 25% with family members (e.g. siblings or cousins). Table 2 shows how each of the three game setups supports specific types of collaboration among pupils. Differences among the setups were clearly noticed in the certain collaboration types such as encouraging, dividing tasks and competing other teams, while the setups were almost similar in reviewing, guiding, and solving together:

Table 2: Types of collaboration among participant groups (N=14).

	***'around'* game setup**		***'in front'* game setup**		***'inside'* game setup**	
Reviewing (n, %)	9	*64%*	7	*50%*	7	*50%*
Guiding (n, %)	7	*50%*	5	*36%*	4	*29%*
Solving together (n, %)	14	*100%*	12	*86%*	13	*93%*
Encouraging (n, %)	**7**	***50%***	3	*21%*	3	*21%*
Dividing tasks (n, %)	**6**	***43%***	2	*14%*	**7**	***50%***
Competing with other teams (n, %)	3	*21%*	**7**	***50%***	**6**	***43%***

Reviewing each other's answers in the three game setups occurred particularly in the 'doing' learning stage, such as when pupils determined whether puzzle pieces are correctly placed in *'around'* game, or whether the cards were true or false in both *'in front'* and *'inside'* games.

Guiding each other by showing one of the correct answers particularly occurred when someone was struggling, such as not knowing where and how to place the cards.

Solving together occurred in *'around'* game only during the 'doing' learning stage by gathering together to solve the 3D puzzle (Figure 9.a). While, it was extended in the other setups to include further learning stages, such as during 'reflecting' stage by checking together at the progress bar (Figure 9.b), and during the 'conceptualizing' stage by switching cards with learning names among themselves (Figure 9.c).

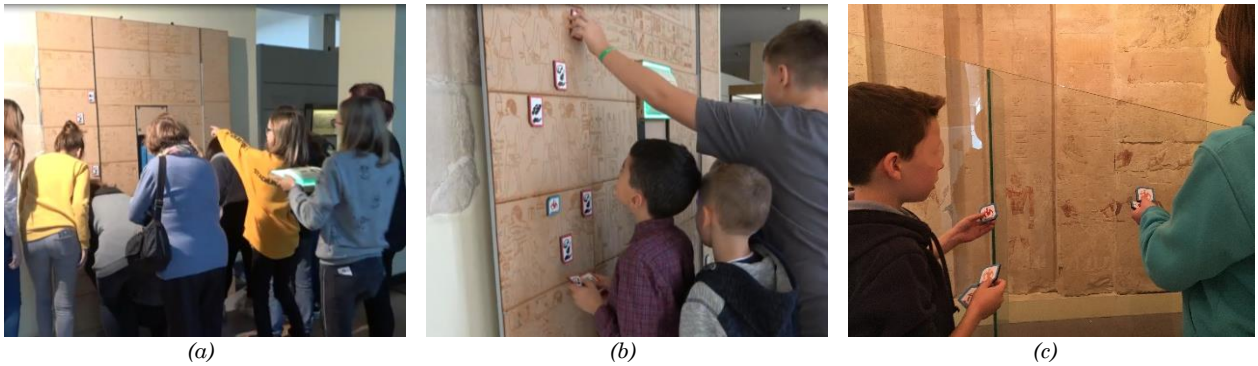
(a) *(b)* *(c)*

Figure 9: Pupils are collaborating to solve the games in groups: (a) several hands in *'around'* game are solving together the 3D puzzle in the 'doing' stage, (b) a group from *'in front'* game during the 'reflecting' stage let someone placing the cards, while another one checking the progress bar, and (c) a girl from *'inside'* game during the 'conceptualizing' stage is switching a man-card with her team-mate from one side to the other side of *TouchTomb*.

Encouraging each other was only noticeable in *'around'* game when a certain pupil is encouraged to get engaged when seeing part of the result appears (i.e. hieroglyphs), and actively collaborates with peers. In contrast, participants of *'in front'* and *'inside'* games were all given cards in hands, so they felt compelled to be engaged from the beginning.

Dividing tasks is obvious in *'around'* and *'inside'* games because these two setups implicitly encouraged pupils to divide tasks among themselves. For instance, in *'around'* game one pupil is always responsible of holding the result piece of the 3D puzzle, while others look either inside or outside the tomb-chapel for the location where to place that result (Figure 10.a), and in *'inside'* game participants tended to assign the responsibility of checking the original colors of the human figures inside the tomb-chapel to some of them (Figure 10.c). In *'in front'* game, we only noticed dividing tasks when a tall boy was responsible of solving the high cards that his peers could not reach (Figure 10.b).

Competing with other teams was not intended in our design, there was no mention of time-tracking, speed or any other explicit indicator that would imply a competition between groups of different parallel games. Nevertheless, the fact that the three games were solved simultaneously by the three teams created a kind of competition around the different groups. That was more noticeable among the teams of *'in front'* and *'inside'* setups because they were sharing the same space, looking at the shared progress bar; *"only three are remaining!"* clearly indicating a comparison and assumed pressure of being left behind.



(a) *(b)* *(c)*

Figure 10: Participants are dividing the tasks among themselves: (a) a girl from *'around'* game was holding the result piece of the 3D puzzle, while another girl was realizing and pointing to the location on *TouchTomb* where to put this result, (b) one tall boy from *'in front'* game who was responsible of solving the high cards, and (c) two participants from *'inside'* game were responsible of going inside the tomb-chapel to check the original colors of the human figures.

5.2.2 *Engagement and appreciation*

In general, participants of *'around'* game spent less time interacting and solving the game (4.1 minutes, avg; 4 minutes, median) in comparison to the participants of *'in front'* game (6.2 minutes, avg; 6.3 minutes, median) and *'inside'* game (6.9 minutes, avg; 7.3 minutes, median). We believe that the idea of having a centered-goal (i.e. solving the puzzle on a table) accelerated solving the game compared to the other games, where pupils were interacting in front a much bigger interface (i.e. *'in front'* game) or even physically going forth and back inside the tomb-chapel (i.e. *'inside'* game). Time was also an indicator of engagement that drove pupils to unintendedly take several weird postures, such as tiptoeing to reach the high cards (Figure 11.b) bending down to place the low cards (Figure 11.c), or sitting on the table while solving the puzzle.

(a) *(b)* *(c)*

Figure 11: Engagement drove participants to take weird postures while participating: (a) three hands from *'around'* game on the same piece of puzzle, (b) a pupil from *'in front'* game tiptoes to put the card in place, while others are checking the progress bar, and (c) participants from *'inside'* game were bending down to place the low cards.

In general, the experience of tangible gamification seemed to be well appreciated by participants of the three game setups and their teachers as well, as demonstrated in percentages of each level of appreciation in Figure 12. All the interviewed teachers appreciated (i.e. 54% like it very much, and 46% like it) the approach of tangible gamification as an interactive educative tool in the museum context; *"I like it because they gain knowledge after interaction, I believe they will remember something from their interaction"* (teacher of Participant 9). They also liked it because children interacted in groups and because of the creativity features.

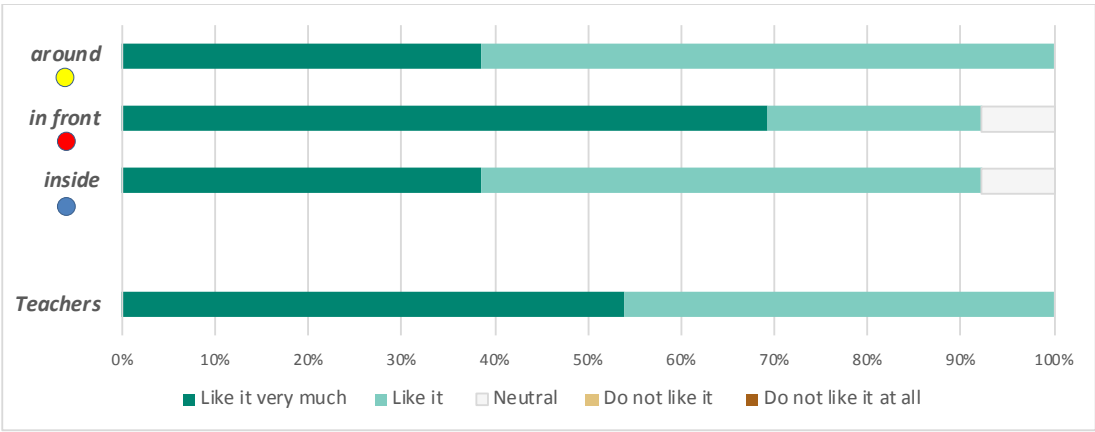


Figure 12: Pupil's and teacher's answers on their level of appreciation (as percentages) documented from the interviews. No percent of the groups reported as "Do not like it" or "Do not like it at all".

5.2.3 *Impact of gamification on user experience*

We noticed that even after we explained the game objectives, there were situations that certain children did not know how to reach them, namely they did not understand the rules of the game. Consequently, we noticed those children learned the rules from their peers by looking and mimicking their actions, such as how to place the cards in *'in front'* game, and where to check the original colors in *'inside'* game. This type of mimicking was noticed in the space in front of *TouchTomb* even while an incorrect original understanding from one of them spread to the team (e.g. placing cards in mismatching locations).

The progress bar acted as a multifaceted game element driving their participation and transferring them from 'doing' to 'reflecting' learning stage, since pupils kept an eye on the progress bar to make sure whether their answer was right or not. The grand, overarching reward of our game design was meant to impact the learning of pupils, as discussed in Section 5.1. On the other hand, the gradual, intermediate reward system directly impacted the user experience. In general, pupils were getting excited when they were rewarded (i.e. having a LED light up). Their excitement was observed individually via happiness facial expressions, verbal expressions *"oh, yes!"*, or even collectively via clapping to themselves. Some pupils were simultaneously looking at the bar when they were placing their own cards (Figure 13.a), while other pupils were dividing the tasks among the group as someone was placing the card and another one was checking the progress bar (Figure 13.b). The progress bar was also used as a check technique for the final result and to realize wrong answers, such as placing all cards but not having all the LEDs lighted on the bar, so pupils reviewed their answers and partially re-solved the game.

(a) *(b)*

Figure 13: Progress bar as a core element of the game (a) an individual simultaneous look at the bar while posting cards, and (b) a collaboration among the team: one is posting the card, while another one is checking the progress bar.

5.2.4 *User experience questionnaire*

All the items of the user experience questionnaire are positively rated from the pupils of the three game setups (Figure 14). The results are formed by a common consensus that all the three game setups were creative and enjoyable, and on the same level of clarity. The *'around'* game is rated as the least informative setup, which conforms to the learning results and the causes in Section 5.1, while pupils found the same game setup as the most attractive because of the luminous puzzle that visually stood out on the wall. The results of easiness seem to correlate with the duration of each game setup, and how the different learning stages were interwoven (Figure 6), so that *'around'* setup is rated as the easiest setup, then *'in front'* and lastly *'inside'* setup.

In general, participants enjoyed answering the questionnaire, we never encountered pupils who refused to participate, but they were jostling each other to receive their LEGO blocks. Due to the limited space around the questionnaire board, they participated team by team, meaning that teams could see answers of previous teams. Teachers explained the questionnaire to pupils and clarified the

meanings of difficult terms (e.g. 'aantrekkelijk' in Dutch and 'attrayant' in French). Although they understood the objective of the questionnaire, they were playing with the LEGO blocks to physically build their own column charts (Figure 4). Pupils tended to loudly express their choices *"I find it very creative" (*Participant 1, *'inside'* team), or *"I think it was a bit easy, but very clear"* (Participant 11, *'in front'* team). Thus, participants were influencing each other in answering the questionnaire not only by seeing the answers of other participants, but also by encouraging each other to choose a specific answer. Similar to their game experience, mimicking each other to learn the rules applies here as well by looking at their peers or asking them.

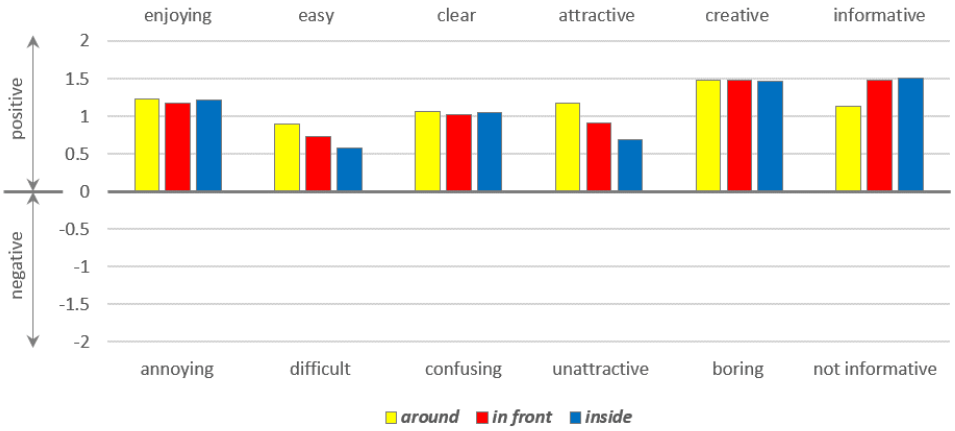


Figure 14: Overall averaged results from the tangible user experience questionnaire, ranging from very positive (2) to neutral (0) and very negative (-2) for the different setups (yellow for *'around'* game, red for *'in front'* game, and blue for *'inside'* game). While all three setups are seen as positive, they differ in how informative, attractive and easy they perceived.

6. DISCUSSION

In this section, we discuss the implications of the results with relevance to future research or potential further developments of tangible gamification in a museum context. We outline several design recommendations based on the qualities of tangible gamification and its role in facilitating cultural learning.

6.1 Situated Tangible Gamification Influences Cultural Learning

The stages of visitors' cultural learning are influenced by the level of situatedness of heritage artifacts in tangible gamification.

Situated communication is denoted on how the information relies on the "physical context" to be understood [Rekimoto et al, 1998]. In heritage communication, the degree of situatedness influences understanding and experiencing heritage artifacts [Nofal et al, 2017]. Our results showed how situating the heritage artifact in the spatial configuration of each game setup influenced how, where and when pupils gained the knowledge. The heritage artifact was obviously contextualized in the 'doing' learning stage in both *'inside'* and *'in front'* game setups, as participants were either directly interacting with *TouchTomb* (i.e. replica wall) or compelled to enter the original tomb-chapel at the beginning of their interaction. While participants of *'around'* setup were not spatially connected to the heritage artifact in their first stage of learning (i.e. doing), and thus they were only playing to solve the puzzle. Further, the remote table of the puzzle decontextualized the learning process, creating a gap between the 'doing' and 'reflecting' stages, and thus delaying their 'conceptualizing' stage, as illustrated in Figure 6. Further, the spatially dispersed tasks caused frustration among the pupils, as

they had to walk first to the *TouchTomb* after solving the puzzle, then to explore the original tomb, and to return back to *TouchTomb*. As a result of the sequential process of learning and the spatially dispersed tasks, *'around'* game was the least informative setup (Figure 8). On the contrary, the spatial configuration of the other game setups allowed for more overlapped learning stages. For instance, the setup *'in front'* enabled pupils to shift from one learning stage to another while interacting in the same space (in front of *TouchTomb*), and then by associating their actions to the heritage context, they managed to reach the 'conceptualizing' stage of learning in an earlier phase of their interaction. Moreover, participants of *'inside'* game setup were compelled to enter the tomb from the beginning of their cycle of cultural learning, and thus the early contextualizing of the heritage artifact interwove their 'doing' and 'reflecting' learning stages. They were accordingly able to conceptualize their interaction by cognitively mapping the physical shape (i.e. human figures) and materiality (i.e. colors) of the artifact itself to the tokens (i.e. gender cards) of the *TouchTomb*. Unlike *'around'* setup, the heritage artifact was situated with a clear goal in the *'inside'* game setup from the early stage of pupils' learning process, resulting in the highest percentage of cultural learning as in Section 5.1 and illustrated in Figure 8.

Consequently, in tangible gamification endeavors for communicating heritage, we highly recommend situating heritage artifact in the early phases of visitors' interaction to allow for interwoven learning stages during their visit. In addition, spatial configuration of tangible gamification needs to be considered in how and when the physical context of heritage artifacts contributes to communicate the information, such as steering natural progression of learning by giving clues.

6.2 Cultural Learning as a Reward of Gamified Experiences

Embedding the intended knowledge to communicate in the reward system of gamified experiences supports informal cultural learning.

Our results show how the gradual rewarding system (i.e. progress bar) influenced the user experience and motivated participants to engage with the installation, gradually preparing for the grand, overarching reward (i.e. the revealed information). The need for intensive collaboration and problem-solving to solve the games, and the balance between the skills and challenge needed to achieve the intermediate goals, created a sense of anticipation for the overarching reward. This anticipation is observed in their rush to complete the tasks, as well as in the drive of the children in the groups of the *'inside'* game setup to collectively engage with the revealed information even when not directed by their teachers. Moreover, our results indicate successful transmission of the intended cultural learnings (as described in section 5.1). This feeling of anticipation and final learning outcomes is comparable to the relation previously established between learning and being in a state of 'flow' [Kiili, 2005]. Moreover, in our case study there were indications of anticipation and learning even at a group level, in which the pupils divided to solve the various intermediate goals and then later re-joined for a collective reading of the revealed information (a *reward* 'given' to all simultaneously).

Accordingly, gamification techniques promise a great potential to enhance informal cultural learning by embedding the knowledge in a form of overarching rewards. Simple intermediate rewards, even of non-educational nature, can be utilized appropriately to retain motivation as well as to build-up anticipation for overall goals of cultural learning.

6.3 Sense of Ownership Causes Accountability

Creating a sense of ownership in tangible gamification motivates museum visitors by making them accountable for solving the game.

We noticed only in *'around'* game a few cases of exclusion, meaning that at least one participant was not involved among the group to solve the puzzle, while in *'in front'* game and *'inside'* game, all participants were involved in some way or form as they were compelled to place their cards. In *'in front'* game and *'inside'* game, cards were not unique, and they were distributed and given to all participants in hands. In contrast, puzzle pieces of *'around'* game were all placed on the table before pupils' participation, then they picked-up one by one to place them on the platform. Thus, this setup allowed for different kinds of aggressive behavior, such as we noticed several times (5, N=14) that one participant started to take puzzle pieces from others' hands as he/she knew where to place these pieces, to the extent that three children started to quarrel to have a certain piece of puzzle (Figure 11.a). Accordingly, a sense of ownership [Hornecker, 2004] was created among participants of *'in front'* and *'inside'* setups. By owning the physical cards, each of them felt accountable for achieving his/her own goal. Unlike the centered goal of *'around'* game setup on one artifact that became more challenging as no individual tasks were assigned, the game goals of *'in front'* and *'inside'* setups were distributed among pupils spatially and even temporally, so they coordinated and jointly determined the order of solving the game.

Consequently, we recommend that museum tangible gamification for young visitors should take into consideration the sense of ownership to make them more motivated and accountable for doing their assigned tasks, as each of their tasks was required to achieve the overall goal (i.e. cultural learning). This sense of ownership can be created when visitors receive physical tokens to interact with, or even by creating their own tokens. Sense of ownership might well be extended from merely tangible pieces or cards to the sense of sharing and owning the physical museum space when the setup of tangible gamification requires physical moving to multiple points of interaction.

6.4 Plurality and Diversification of Goals Fosters Collaboration

Collaboration among young museum visitors can be fostered in tangible gamification when it includes multiple and diverse goals distributed in space and time.

Using three game setups that can run simultaneously for three teams enabled us to engage all the classroom pupils on a group level, having separate goals to achieve. The setup of the game thus created a kind of competition among pupils (see Section 5.2.1). Though this competition was not intended in our design, since it emerged simply from calling the process a 'game' and sharing a progress bar. In effect, even though we documented competitive reasoning between teams, in each of the teams separately, we noticed collaboration practices that engaged all the individuals of each team since there were too many intermediate goals to be successfully achieved without coordination. Moreover, we observed that spatial diversification such as having to add the cards higher or lower to the ground allowed for different types of pupils in each team (e.g. of varying heights) to actively participate and collaborate in an inclusive way. The existence of multiple goals that were also spatially distributed, enabled all pupils to participate in the process, both individually and as a team thus making the 'game' an active element in their museum visit.

Tangible gamification in museums is orchestrated by embedding varying intermediate tasks that can be distributed in space and time. So, all visitors are engaged and can collaborate with each other depending on their features, interests, or assigned tasks. This orchestration should be designed based on the existing situation to determine the spatial and temporal distribution of tasks. For instance, visitors do not have to do everything all at once and overwhelm the infrastructure, thus physical clashing with each other can be avoided.

6.5 Playful Evaluation

Playful and collective questionnaires enable the evaluation of children's user experience in a short time and in loaded environments.

Our results showed how young museum visitors considered the tangible questionnaire playful and enjoyed answering it, as explained in Section 5.2.4. Associating the design of the questionnaire to their play experience (i.e. physical LEGO blocks) implicitly informed them what they must know and do in order to play and answer it [Salen and Zimmerman, 2004]. We argue that this kind of questionnaire differs from conventional and individual surveys (i.e. paper-based and screen-based) in terms of (a) allowing and motivating pupils to collectively evaluate their experience in a very short time, and are thus possible in loaded environments, as shown in Figure 15.a, (b) using familiar gaming techniques to answer the questionnaire allows for playful and creativity aspects (Figure 15.b), (c) physically visualizing the answers allows for a potential comparison among the peers and thus reflecting on the different teams, and (d) similar to the game itself, distributing the physical tokens of the questionnaire (i.e. LEGO blocks) to participants creates a sense of ownership by making each of them more committed to answer all questions, as discussed in Section 6.3. On the other hand, we acknowledge that this kind of questionnaire might create more biases in the results since participants are influencing each other not only passively by seeing the answers of other participants, but also actively by diverting each other to change their answers. Further, LEGO's are associated with a playful experience which can in this case hinder the need for more accurate or representative documentation.

Consequently, we recommend using playful and collective surveys in order to collect intense data from children and to evaluate their experience in loaded environments. Yet, these collective surveys might be biased since participants see each other's answers, but possibly truthful based on a shared understanding. We recognize that further studies are needed to ensure the validity of collective and playful questionnaires, and to investigate whether playful methods of evaluation could also stimulate children to report on other types of information (e.g. their cultural learning).

(a) *(b)*

Figure 15: Qualities of the questionnaire: (a) participants are collectively answering the questionnaire in a loaded environment, and (b) a group of participants express their answers in a playful and creative manner.

6.6 Shortcomings and Limitations

In our study, the experiments were deployed for a limited time in a real-life busy environment with a relatively large number of participants. Our participants were all young visitors (10-14 years old), who were relatively easy to motivate, yet hard to control and challenging to interview due to lack of focus and language barriers. At the same time, we believe that most of our findings can be generalized

towards many other forms of tangible gamifications that are meant to communicate or educate heritage information towards young visitors.

Moreover, the intended cultural learning goals of our three game setups might not be equal in terms of easiness and interest, however we did not aim to compare the three setups out of viewpoint of effectiveness, rather to recognize intrinsic differences and their impact on learning and visitors' engagement. Due to the time limit, we were not able to ask our participants individually, we accordingly conducted the interviews in groups. In the group interviews, it was very challenging to ensure that all 5 pupils within a group have gained the same knowledge from their interaction, but we assumed that their collective answers might well contribute to the ultimate objective (i.e. cultural learning). Further, we did not notice a clear evidence that different teams learn from each other due to the limited time or the pressure of the unintended competition. However, further studies are encouraged to benefit from this 'missed' opportunity and to investigate whether the approach of tangible gamification causes an indirect learning among participants, for instance by transferring the knowledge from one game team member to a person in another team. Moreover, for a better assessment of cultural learning, we did design a post-interaction survey and sent it to certain teachers, who showed the interest and willingness to ask their pupils few questions about what they learned from their museum gamified experience in the following week. But unfortunately, none of them responded back to us. So, we relied only on the on-site interviews to evaluate the cultural learning of participants.

7. CONCLUSION

In this study, through a field study in a real-world museum environment, we presented *TouchTomb*, a tangible gamification installation that aims to communicate different types of tacit knowledge of an ancient Egyptian tomb-chapel in an informal cultural learning setup. We deployed a mixed-methods evaluation study to investigate how *TouchTomb* enhances the cultural learning of a total of 190 young museum visitors (pupils of 10 to 14 years old), and we examined the collaboration and engagement of visitors during their interaction flow that lasted for maximum 15 minutes, and how it affects the different stages of their cultural learning and enhances their museum visiting experience.

Our findings show several qualities of applying the approach of tangible gamification in museum context, such as enhancing informal cultural learning of young museum visitors by considering the physical context of heritage artifact in their interaction, and fostering engagement and collaboration among them by embedding varying intermediate tasks that can be distributed in space and time. We concluded the paper with a set of discussion points and design recommendations for future research or potential further development of tangible gamification that educate or communicate heritage in museums for young visitors, such as: situating heritage artifacts in cultural learning, including the learning in the reward system, engaging visitors by enabling them to own and to be accountable for their physical tokens, fostering collaboration among them by having a diversity of goals, and evaluating their experience in a playful and collective way.

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