Journey through the pyramids of Giza.

An Augmented Game for the Plateau of Giza

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ABSTRACT

This paper focuses on the feasibility of a system for the model of the Plateau of Giza, which is part of the archaeological collection of the Allard Pierson Museum. The museum wishes to make the model more interactive, more educational and more attractive to children. With this aim a system was conceptualized and a fully functional prototype was made. The interactive system designed is an augmented serious game that educates the users about the building process of the pyramids of Giza. To answer the research question "Is an educational augmented reality game a suitable solution for the aspiration of the Allard Pierson Museum to make the model of the Giza plateau more interactive?", the final prototype was tested with 16 children in the age from 8 till 12. The results of the final test indicate that the children find the game entertaining and that compared to what they know before playing the game they have learned something new after playing the game. Concluding that the prototype is educational, entertaining and interactive it is a suitable solution for the Allard Pierson Museum's objectives.

1. INTRODUCTION & MOTIVATION

The era of digitalization has brought along numerous disruptive innovations, which have caused a shift in how information is transferred and received. In recent years, new technologies have enabled to create new experiences and to reach a larger audience. Despite the emerging possibilities, it has also become a challenge for organisations and foundations to adapt existing strategies to these new technologies. The Allard Pierson Museum is an archeological museum, which is part of the University of Amsterdam. Although the museum occupies an interesting collection on the ancient societies, the museum aims to increase the interaction between the collection artifacts and their visitors, and to attract a wider audience. For this reason, the museum desires to renovate the Ancient Egyptian department in 2018. With the focus on the renovation, the museum aims to draw the attention of families with young children with renewed ideas for an interactive experience with the collection. The museum aims to provide their visitors an unique experience and to educate them on the importance of the ancient civilization to the contemporary European culture with a more engaging and dynamic approach.

This paper proposes the concept of an interactive augmented reality game for families with children between 8 and 12 years. The project is centered around one prominent element of the collection: the model of the Giza plateau, which is eminent for the impressive pyramids. The aim of the proposed concept is to enable interactions with the model and to effectively convey historical information regarding the ancient Egyptians pyramids. This leads to the following research question: "What is a suitable educational solution for the aspiration of the Allard Pierson Museum to make the model of the Giza plateau more interactive?".

2. RELATED WORK

2.1 Serious gaming

A game can be classified to consist of three aspects: gameplay, game rules and game world: "Gameplay deals with strategies and motives of the player, game rules deal with the rules and structure of the games while game world deals with the fictional contents of the games" (Ang, Avni, & Zaphiris, 2008, p. 534). Through the gameplay, the user aims to "exert efforts in order to influence the outcome" (Juul, 2010, p. 255). Serious gaming can be distinguished as games "in which education (in its various forms) is the primary goal, rather than entertainment" (Michael & Chen, 2005, p.17). Serious gaming as a concept shows the possibility for users to learn through gameplay, in an informal setting at their own pace, and without the need of support (Lunn et al., 2016).

Employing serious gaming can be more effective than 'teaching as telling'. Serious gaming allows for interaction with information and thus leading to deep understanding through time, reflection and active engagement (Young et al., 2012). Serious gaming is especially effective for teaching and training since it enables the communication of concepts and facts, while allowing the users to "assume realistic roles, face problems, formulate strategies, make decisions, and get fast feedback on the consequences of their actions" (Michael & Chen, 2005, p.25-26).

2.2 Augmented Reality

A related topic that is commonly associated with serious gaming is augmented reality (AR). AR uses virtual objects in real environments (Van Krevelen & Poelman, 2010).

It can be implemented on various mobile platforms, for example on mobile phones, tablets or computers.

Augmented reality is especially suitable in a learning context as a solution for users who experience difficulties in visualizing unobservable phenomena (Wu, Lee, Chang, & Liang, 2013). "One of the most promising potential applications of augmented reality is to provide explanations of, and assistance with, complex 3D tasks" (Feiner, Macintyre, & Seligmann, 1993, p. 54). With AR the user interacts with the content in a three-dimensional perspective, which enables the user to enhance understanding of the content from an individual perspective. In addition, AR stimulates thinking skills and conceptual understandings by means of virtual and real environmental-related factors. AR bridges the gap between formal and informal learning (Wu et al., 2013).

According to Feiner et al., learning through augmented reality has 3 communicative goals: to show, locate and identify (Feiner et al., 1993). This allows for information to be shown visually in a more real-world and tangible context. Research has proven that significant performance for knowledge acquisition and retention were achieved by museum visitors when interacting with augmented exhibits (Sommerauer & Müller, 2014). Furthermore, the visitors perceived "augmented reality as a valuable and desirable add-on for museum exhibitions" (Sommerauer & Müller, 2014, p.59). Thus augmented reality provides an opportunity to extend the learning benefits of serious gaming.

2.3 Memory, recall and recognition

Based on the multi-store model of memory, it can be said that the human memory consists of a short-term/working memory and a long-term memory (Benyon, 2010). Working memory can be distinguished for its ability to store information from temporary experiences, while long-term memory is able to store memories that may last a lifetime (Benyon, 2010). The model of memory is important as it provides a better understanding on how information as learnt through gameplay could be stored for improved learnability.

Recall refers to "the process whereby individuals actively search their memories to retrieve a particular piece of information", whereas recognition "involves searching our memory and then deciding whether the piece of information matches what we have in our memory stores" (Benyon, 2010, p. 539). In other words, recall is practiced whenever the user is trying to remember the information he/she has seen through gameplay. Alternatively, a user is practicing recognition whenever he/she is trying to find the correct answers to questions asked in a game. Memory retrieval with both processes can be activated through cues. Recognition is easier than recall, since recognition involves a higher amount of cues, which increases the chance for activations (Budiu, 2014).

The activation of information in the memory is affected by (1) the amount of times the same information has been activated, (2) the recency of retrieval, and (3) the context (Budiu, 2014). Memory retrieval can be improved through techniques such as chunking and rehearsal. The information can be split and organised into smaller, more meaningful groups through chunking. Furthermore, rehearsal or repetition of information helps to refresh the content (Benyon, 2010).

2.4 Museum interaction and learnability

Museums are commonly portrayed as public spaces for adults for quiet contemplation. However, current museums attempt to transform this concept to a more interactive experience. The human attention is attracted by novel stimuli (Csikszentmihalyi & Hermanson, 1999), such as a mysterious object. This enables the museums to captivate the visitor's attention, which could lead to the acquisition of actual knowledge. While technological novelty does not necessarily attract more visitors, according to Sandifer's findings (2003), it does increase the amount of time they spent at the exhibition.

One approach to establish interactivity is through multimedia applications. According to Economou (1998) the power of multimedia application can be a stimulants for visitor attraction (Economou, 1998). The research findings show that the appeal of the medium can help the visitor to receive and understand the information in a more effective approach. Nonetheless, the emphasis of an exhibition has to be on the distribution of information, not on the medium. Economou also discovered that multimedia applications have particular strengths for archaeological displays. Multimedia applications have the ability to provide an idea of the object's original context, as well as an explanation of the object itself (Economou, 1998).

3. METHODS

For this abductive research, an iterative approach has been taken in combination with the double diamond method. The double diamond method provides a methodology to first explore multiple diverse concepts and designs, and to follow-up through converging to specific ideas. Furthermore, the iterative approach allows for a better understanding of stakeholders and the resulting requirements, and to implement user feedback into the concept for a more reliable evaluation. Therefore, the process consists of four important phases: (1) stakeholders understanding and requirements, (2) conceptualization, (3) implementation, and (4) evaluation.

Firstly, (1) a stakeholder analysis and a PACT analysis have been conducted to identify the involved stakeholders in addition to their concerns and needs. The analyses help to choose the right target group as user of the system, and to formulate requirements that are to be covered by (2) the interaction and system design. Subsequently, (3) the concept is concretized and implemented, followed by (4) an evaluation for usability and effectiveness for learnability. This iterative process also consisted of a pre-test. The pre-test highlighted design elements that had to be changed in order to improve the user experience. In the final test the final application was tested on the user experience and the learnability. The user experience was evaluated according to the Nielsen Heuristics (Alsumait & Al-Osaimi, 2009).

The final test consisted of semi-structured interviews with the users. The purpose of these in-depth interviews was to measure the user experience of the game and the related learnability.

3.1 Stakeholders Understanding and Requirements

In order to design a system that is able to meet the client's requirements, it is important to have a good understanding on the various stakeholders that are affected by the system, and to identify the system requirements.

3.1.1 Stakeholder Analysis

The various stakeholders are identified and categorised in Table 1. Through discussions with involved parties within the museum, it was possible to list the important stakeholders and their concerns. Subsequently, a strategy is devised which entails the considerations that are to be taken into account during the design process.

While all identified stakeholders in Table 1 are of importance, the degree of direct involvement differs. Two types of main stakeholders can be identified:

1. The **museum representatives** (of the Ancient Egypt exhibition) that are directly involved are the **project leader** of redevelopment and the curator. Identifying the museum representatives helps to introduce requirements with aim to align the system with the objectives of the museum.

2. Since the **main users of the system** consist of children (between 8 and 12 years) and their **parents**, these two stakeholders can be identified as the main stakeholders of the system. In particular, design decisions should be made by considering the needs of the children.

Both types of stakeholders have direct implications on the system design and introduce limitations that should be taken into account for. Since the system is mainly to be used by children, the choice has been made to largely focus on children as the main users of the system for the design process. Nonetheless, decisions made throughout the process are also based on requirements as introduced by the museum representatives.

3.1.2 PACT Analysis

The PACT Framework provides a human-centred approach to identify the people, activities, contexts and technologies that need to be taken into account during the design process (Benyon, 2010). Employing the PACT Framework enables to define a scope and the requirements for the resulting system design.

People.

Since the system is aimed at children in the age group of 8 to 12 years, the system should be easily understandable. Furthermore, since visitors of the museum may originate from various countries, it is important to consider language differences. The system should be designed to allow for extensibility of new materials to keep the different type of visitors, which can range from occasional to frequent visitors, interested.

Activities.

The main purpose of the system is to educate users on the Ancient Egypt through an entertaining approach. Since there is only a single pyramid model, the space is limited. Therefore, the amount of users that are able to interact with the system should be chosen by taking the limited space into account. On the other hand, multiple visitors should be able to use the system simultaneously. Subsequently, the children should be able to use the system individually and be able to participate at any time.

Contexts.

Since the system is to be used in the museum, the physical environment and social context should be taken into account. An indoor setting within the museum implicates that the text in the system should be readable. Furthermore, the system should also be usable in a less quiet environment. Although the user should be able to use the system individually, it should also encourage interactions with other accompanying families and friends, and other visitors.

Technologies.

Since most portable devices nowadays are touch devices, the system should similarly accommodate for touch input to allow for direct manipulation. Furthermore, the system should provide for both graphical and textual output to transfer learning materials in an understandable and entertaining way for children.

4. INTERACTION DESIGN

4.1 Requirements

The requirements are derived from the stakeholder analysis as well as the PACT analysis. The MoSCoW-method provides an overview of these requirements (Van Vliet, 1993). The requirements for this project are shown in Table 2. The essential requirements to achieve the main goal are labelled as 'must have'. The 'should have' requirements are preferable and the 'could have' elements are optional. The privacy of the user is guarantied by the measure that the information and pictures of the users are not stored permanently. The information and pictures are deleted when the user signs out. The requirements labelled as "won't have" will definitely not be implemented for privacy reasons.

4.1.1 Concept

In order to meet the requirements, multiple aspects are taken in consideration. The choice to make an augmented system is motivated by the desire to conserve the experience of the original model. In addition, the concept of a game would be attractive to children and it would be suitable to achieve the educational purpose. The extension of the additional educational and attractive experience combined with the non-interrupting aspect of the current artifact were the main motivations for conceptualizing an augmented serious game.

The concept of the complete product consists of four augmented reality (AR) games, with aim to lead the visitor through the various aspects of the existing model. Within the model of the Giza plateau there are several areas with different learning objectives. Considering the many interesting subjects surrounding the Giza plateau the development of more serious games would be suitable. The games that have been conceptualized are:

- Building the Pyramids: the user learns about the

Table 1: Stakeholder Matrix

Stakeholder	Concerns	Role Type	Strategy
Director of the Museum Allard Pierson	To attract more visitors with limited budget and resources.	Monitor	To consider financially, realistic options.
Project Leader of Redevelopment	To modernize the museum interaction models	Keep satisfied, and keep informed	To think creatively, to consider technologically advanced techniques, and to keep her informed with regular updates.
Curator	To transfer the correct knowledge to visitors on the Egyptian history, primarily the pyramids.	Keep satisfied, and keep informed	To conduct thorough research on the Egyptian history. To consider his current plans for the redevelopment of the Egyptian department within the museum.
User (children)	To be entertained	Key player	To take their mindset into account, and to make the system accessible and fun for their age group.
User (parents)	For their children to gain cultural enrichment.	Key player	To make the system educational, and to evoke cultural awareness.

Table 2: Requirements

Requirements
Must have
1. The user must be able to understand the text. 2. The user must be able to understand the interaction model. 3. The user must be able to receive feedback on the chosen answer. 4. The model must contain a tablet on each side of the model. 5. The user must have access to at least three sides of the model. 6. The user must have free access to the model, without the presence of a glass containment. 7. The model must have good lighting.
Should have
8. The application should have access to a good Wi-Fi connection. 9. The application should have multiple language options. 10. The application should have a reward system.
Could have
11. The application could make use of audio to read the text out loud. 12. The application could contain more games. 13. The application could have a score ranking system.
Won't have
14. The system will not store personal information or pictures after the user has signed out.

different aspects for building the pyramids of Giza.

- Mummification Ritual: the user learns about the mummification ritual for deceased pharaohs and their beliefs in Egyptian Gods.
- Boat Journey: the user learns about the transportation of materials through the river Nile.
- Discover the tombs: the user learns what the pyramid looks like on the inside and the different functions of the various chambers.

In order to engage the user more intensively and to increase the interaction with the existing model, the games make use of AR technology. Since the games are present at the model site in a non-disruptive way, the concept also allows visitors to interact with the model without using the game. This is especially suitable for visitors who would observe the model, without having to cope with modern technology.

When the user takes one of the tablets, the user is asked to enter his or her name and to choose English or Dutch as the preferred language for personalisation and adaptability to a specific user (Figure 1). Following, the main menu includes four options: new game, resume game, score, and sign out (Figure 2). The options "resume game" and "score" are inactive when the user has not played a game yet. By selecting 'new game', the scan feature appears and the user has to find the object in the model which can be scanned.

Figure 1: Name

When the user selects the help button, he or she is shown a map of the model and the following message: "In the model of Giza there are four objects which can be scanned. Each object leads you to a different game. Find the object and place your tablet in front of the object to scan it." In the map the scan-able objects are highlighted to give the user a hint on the position of the objects. After scanning an object in the model, one of the four games is activated.

Figure 2: Menu

Figure 4: Feedback

During gameplay, the user has to answer several questions regarding the Giza plateau. Some of the screens are projected through augmented reality, while others use a static background. The user has to have the camera aimed on the object, since the animations are augmented (Figure 3). A text is shown to remind the user to scan the pyramid and to keep the camera on the same position. The multiple choice questions in the game enable the user to think and acquire knowledge on the Giza plateau. When the user selects an answer, the answer is, when suitable, shown to the user by using an augmented animation. Such an animation allows the user to obtain fast feedback through visualization, and thus prompting for assessment of their decisions within the game. If the selected answer is incorrect, the user receives direct feedback and textual explanations, which allows the user to select a different answer accordingly (Figure 4). In order to help the user, the incorrect answer

Figure 3: Animation

disappears so the user cannot choose the same answer repeatedly. This allows for error prevention, since it prevents the user from being confused about why an answer is not recognized. In addition, the game is designed to also place emphasis on positive feedback: when the user selects the correct answer, he or she will receive additional information about the subject.

Once reaching the end of the game, the user is able to see the obtained score for that specific game (Figure 5). Each independent game has a different scoring method, which is related to actual known facts on that topic. In order to reward the user as a form of positive feedback, and to stimulate the brand awareness of the museum, the user is shown his or her achievement followed by the ability to take a special picture of himself or herself. All games have their own photo-frame within the theme of the game, for example the "Building the Pyramids" game enables to user to take a photo with pharaoh Khufu and his pyramids(Figure 6). The picture can be shared through social media or e-mail.

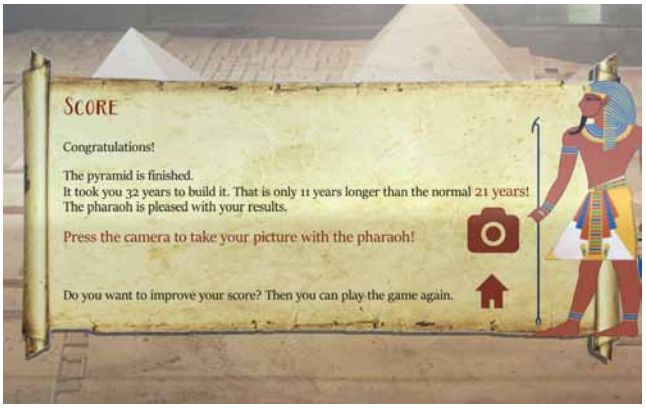

Figure 5: Score

Figure 6: Photo

While multiple games are introduced as part of the concept, the choice has been made to limit the scope of this paper to the primary game to validate the usability and learnability before implementation of the remaining games. Therefore, the further sections of this paper will focus on the specific design and evaluation of the game where the user will build a pyramid for pharaoh Khufu, namely the "Building the Pyramids" game.

4.2 Design

The "Building the Pyramids" game is aimed for the user to learn about the process of building the Giza pyramids. The game consists of three consecutive phases:

- Phase 1: Planning to build the pyramid
- Phase 2: Prepare to build the pyramid
- Phase 3: Building the pyramid

Figure 7: Start Game

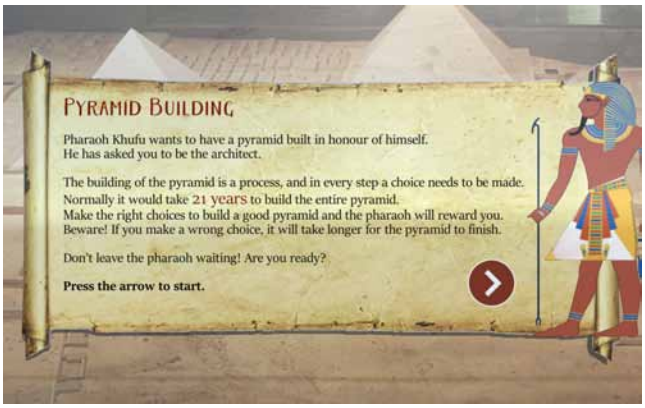

Figure 8: Instructions

The three phases in the game are symbolized as three layers in the resulting pyramid. In each of the augmented scenes, an overlay is placed over the pyramid in the model. The overlay shows the user's progress in the game symbolized by the amount of layers that have been built so far. With every layer the overlay is removed bit by bit, making more of the pyramid in the model visible ((figure: 12), (figure: 15), and (figure: 17)).

The user activates the building game while scanning the pyramid, which is followed by a request for the user to start the building game (Figure 7). Once the user decides to continue with the game, the introduction (Figure 8) will be shown. The user receives information on the scoring method. The best obtainable score is the average time needed to build the pyramid, which is 21 years time. With every incorrect answer, one year is added to the score, which represents a building delay.

Phase 1: Planning to build the pyramid.

Phase 1 of the game consists of multiple choice questions, where the user acquires knowledge on the planning phase. In this phase, the user learns about the location (Figure 9), workers (Figure 10), and materials (Figure 11) that were required to build the pyramids. Once reaching the end of the phase, the user is able to see that the first layer of the pyramid has been built (Figure 12).

Figure 9: Location

Figure 10: Workers

Phase 2: Prepare to build the pyramid.

Phase 2 of the game also consists of various multiple choice questions, where the user learns more about the preparing phase. During this phase, the user acquires actual knowledge on the processes to collect (Figure 13) and to transport materials (Figure: 14) as preparation for the building process. Once reaching the end of the phase, the

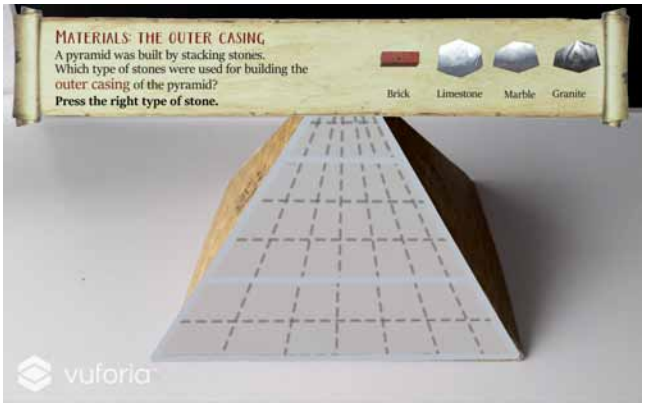

Figure 11: Materials

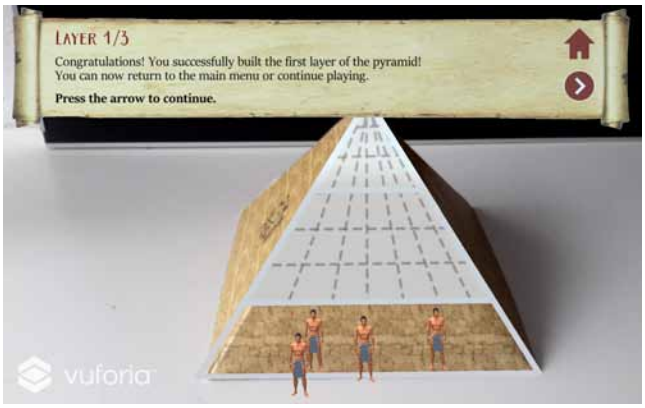

Figure 12: LayerOne

user will be able to see that the second layer of the pyramids has been built (Figure 15).

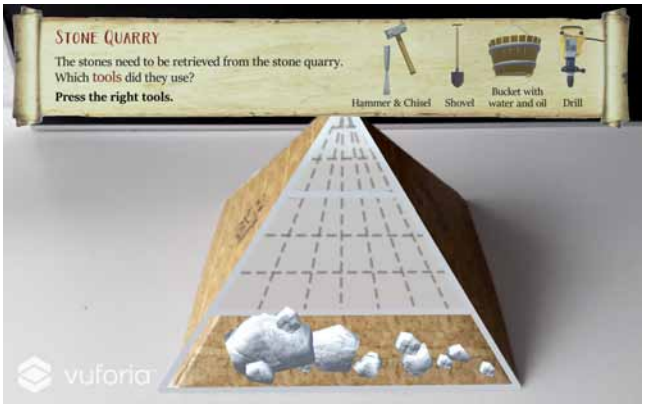

Figure 13: Quarry

Phase 3: Building the pyramid.

Phase 3 is the last phase and consists of a mini game where the user acquires knowledge on the finalization of the building process. In the mini game, the user walks with the skilled worker to the pyramid where the other workers are waiting to pull the sled to the top of the pyramid,

Figure 14: Transport

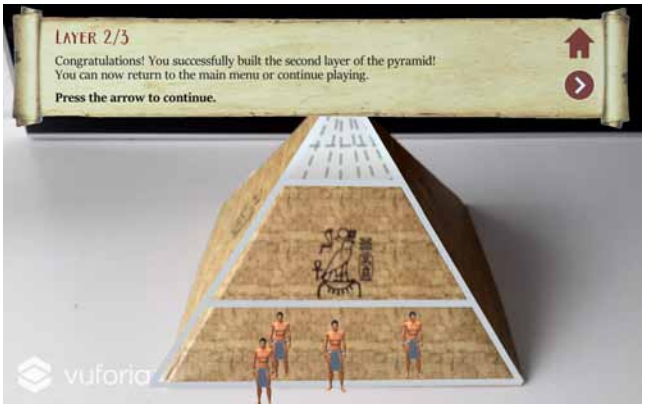

Figure 15: LayerTwo

which is called the pyramidion (Figure 16). The challenge for the player is to keep away from the edges of the path. The mini game is added into the game design to provide a stronger game element and to stimulate attention through introduction of a different kind of game style. Similar to the previous phases, the user is shown that the third (and last layer) of the pyramid has been built (Figure 17).

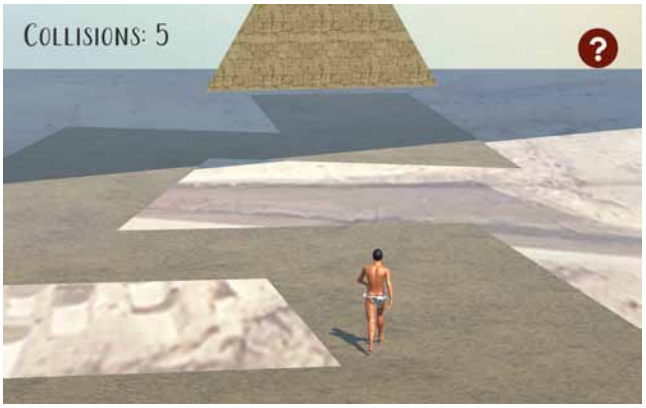

Figure 16: MiniGame

5. SYSTEM DESCRIPTION

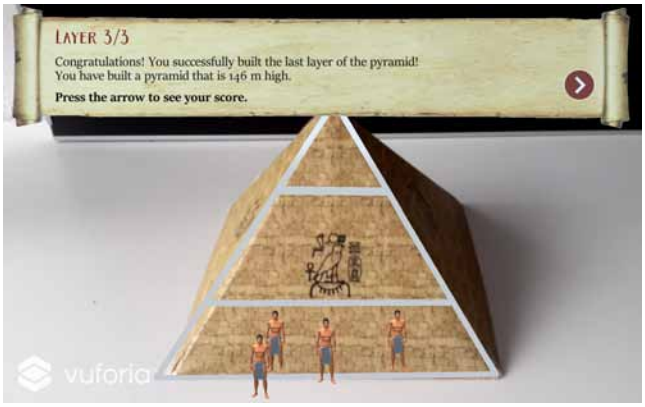

Figure 17: LayerThree

5.1 Hardware

For the game to work properly the hardware requirements are as follows:

- availability of tablets (a minimum of 1-4 touch devices)
- a pyramid model with an attached augmented reality marker target
- access to good lighting

The game application should be downloadable and installed on a portable device, preferably directly through the Play store or App store. A different approach is to manually transfer the application as an APK-file through the computer. The game can be played on various portable platforms, such as tablets or smartphones. Multiple tablets enable multiple players to interact with the model simultaneously. A pyramid model with the marker target, one on each side, is used to activate the game and the augmented scenes. In order to enable the scanning of the marker target, good lighting on the pyramid model is essential. Furthermore, the information and pictures of the users are not permanently stored on the device, guaranteeing the privacy of the user. The user's information and pictures are automatically deleted when he or she signs out.

5.2 Software

5.2.1 *Prototype implementation*

The prototype was developed through two software applications: Unity[1] and Vuforia[2]. These software applications enable to build a game with non-augmented and augmented scenes. The Unity software allowed for game elements to be built through two different approaches. Firstly, the software was used to make animations. Secondly, Unity enabled scripting with Java and C#, and C# was specifically chosen to be used for the development of the game.

The Vuforia software enabled to develop the augmented game features for the game. Although Unity provides the ability to develop static game scenes, the Vuforia add-on offers a software application for developing augmented scenes.

[1]https://unity3d.com
[2]https://www.vuforia.com

5.2.2 *Feasibility for Allard Pierson Museum*

For the system to be implemented in the future it is recommended to use other professional software applications for the development of the (augmented) game. The expectation is that the quality of the game features, for example the scanning of the object, would improve by using more advanced software. For the final implementation it is essential to verify the information within the games through the help of the educational department of the museum, in order to guarantee the correctness of the information in the games.

If the prototype would be implemented in the Allard Pierson Museum some other hardware requirements are applicable as well. Firstly, the model would need to be accessible from at least three sides, or preferably four sides. Consequently, the glass containment that is currently surrounding the model, should be removed. In addition, the museum would need to provide a minimum of one to four tablets, preferably at least one on each side of the model. Lastly, the model would need good lighting in order to allow the marker target to be properly scannable. Furthermore, it is desirable to have access to a good Wi-Fi connection, a server and a database for the implementation.

5.2.3 *Feasibility for Allard Pierson Museum*

The system should be maintained by either the museum or a third party. Dependently on the chosen implementation, it could be possible to make use of 'easily accessible' software (for example Unity and Vuforia), which allows for simple maintenance by students, for example. Furthermore, adapting the games or adding games could be easily achieved when chosen for this 'easily accessible' software. However, the expectation is that the quality of the system would increase when developing the system with use of more advanced software. When chosen for more advanced software, the system should be maintained by professionals.

6. EVALUATION

After conceptualization, the concept was evaluated through a pre-test and a final testing. A mock-up of the application was created for a usability pre-test. In addition, the final prototype of the product was tested on both usability and learnability. The pre-test as well as the final testing used semi-structured interviews to evaluate the application's performance on the aforementioned features. The details of these interviews are divided into and described in the subsections for the pre-test phase and the final testing phase.

6.1 Pre-test

6.1.1 *Design*

To measure the user experience of the application, a pre-test has been conducted. The temporary game consisted of a clickable mock-up, wherein all the game questions were implemented with simple animations. The test was mainly focused on the usability aspect, in particular the understanding of the first three 'must have' requirements: "The user must be able to understand the text", "The user must be able to understand the interaction model" and "The user must be able to receive feedback on the chosen answer".

6.1.2 *Participants*

According to the stakeholder analysis and the PACT analysis, the most important stakeholders that are targeted for the game consist of children between 8 and 12 years old. Therefore, in the first session two children, a boy of age 9 and a girl of age 10, were chosen to test the mock-up, as well as one boy of age 10 in the second session. These participants were chosen using purposive sampling in order to sample relevant stakeholders.

6.1.3 Procedure

The mock-up was tested in two sessions. In each session the setting of the application in the museum was explained before playing. While playing the subjects were encouraged to go through the screens as autonomous as possible. However, they were, allowed to ask questions if necessary, to ensure completion of the entire test. Once testing with the mock-up has been completed, the subjects were asked to give their opinion on the usability and their perceived experience of the game.

Given that the pre-test was only done twice with aim to gain preliminary feedback, the users' reactions and answers to the interview were not coded but were taken as direct input for improvement of the game.

6.1.4 Materials

A clickable mock-up (Figure 18) has been made using the wireframing tool InVision[3]. The mock-up enables the user to go through the game process, but is also limited to a specific ideal path. Therefore, the user is only able to choose certain pre-set choices. Furthermore, since it is a mid-fidelity preliminary prototype no augmented elements have been incorporated. However, the augmented animations have been mimicked in the form of simple image animations to gauge the user experience and perceptions, in preparation for the final prototype implementation.

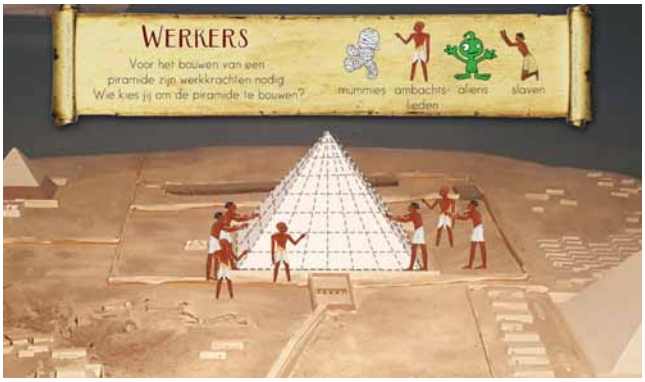

Figure 18: MockUp

6.1.5 Results

A few exemplary fragments of the interviews that have been used as input for the improvement of the design are available in table 3. The entire interviews can be found in the appendix.

6.1.6 Conclusion

[3]https://www.invisionapp.com/

Table 3: Pre-test interviews

	Document 1: "Document "Pre-gebruikerstest: 10-01-17"	
1a	Interviewer M:	Do you know where the river Nile runs?
	Child B:	Is this the Nile River?
	Interviewer M:	Do you see him already? No? Do you already know what the west side is?
	Child B:	Is that compass there correct?
	Interviewer M:	Yes that one is accurate.
	Child B:	Okay then the west is there.
	Interviewer M:	Yes that is correct. Well if you see the pyramids like this, then that has to be the west of the Nile, near the big city Memphis.
1b	Interviewer M:	Very good. This is where you could see the cracks. Look, and this is where you could see the hint. So: "To carve out the stones the Egyptians used sharp tools". Did you realize that meant you should choose the pick axe? Or is this too late?
	Child B:	This is too late.
	Document 2: "Pre-gebruikerstest: 09-01-17 "	
2a	Interviewer S:	And if you click on something that is incorrect, do you like it that they don't tell you immediately that it is wrong?
	Child:	Ehm yes.
	Child:	Or if...
	Child:	Well no.
	Child:	Well no I don't like that.
		[...]
	Child:	But then you are sure the next time that that is the answer
	Child:	But you can also just say that it is wrong
2b	Interviewer S:	[...] Congratulations it took you 32 years to build the pyramid. [...]
	Child:	32 years?!
	Child:	32?

Following the the pre-test, the design of the product was improved on three main points. The sentences were constructed in a more straightforward way, the layout of the texts was reorganized, and the interaction provided earlier feedback on the choices made by the user.

Layout.

Fragment 1a of the pre-tests illustrates that the presence of the compass in the question was not explicit enough. The child needed more instructions than were provided in the game. In addition to a clearer layout on the images, the layout was also improved on terms of sentence constructions. A simple example of this is the sentence construction of the second question in the game: In the mock-up the question is formulated as "Who will build the pyramid?" (door wie zal

de piramide gebouwd worden?), which is improved to "Who of the following workers is most suitable for the building of the pyramid?" (wie van de volgende werkkrachten is het beste in het bouwen van piramides?).

Feedback.

The results of the pre-test indicate the desirability and importance to provide feedback on the questions earlier in the game. This is evident from fragment 1b and 2a. In fragment 2a the children are negotiating the benefit of earlier feedback, weighing the understandability against the disappointment of not being able to find out the answer on their own. To try and keep both advantages, the final prototype provides the feedback instantly without the correct answer is being given.

In addition to timing, the amount of detail of the feedback has also been improved in the final prototype. In fragment 2b both children were astonished by the amount of time it took to build the pyramid. This pre-test indicated that the default time it takes to build a pyramid, 21 years at least, was unclear for the children and thus led to them being unpleasantly surprised. This was the motivation to take a closer look at the details of the feedback texts.

7. FINAL TESTING

7.0.1 Design

In order to measure the final user experience and the learnability of the game, a final test was conducted by allowing participants to play with the game freely, followed by a semi-structured interview. The user experience was again measured using the Nielsen's Heuristics as a guidance for the design of the interview. In total 9 out of the 10 heuristics were used in the interview design. Subsequently, additional questions were included with focus on the content of the game, in order to measure the learnability.

7.0.2 Participants

The final test was conducted on a primary school with sixteen children between the age 8 and 12. The test was done in 4 rounds, in which 4 participants from the same grade were divided in a specific round. The first four were chosen from the 8th grade ('groep 8'), the second four from the 7th grade ('groep 7') etc. with the last round consisting of children from the 5th grade ('groep 5'). All the children per grade were randomly chosen by their teacher, to provide a more representative sample group for the research.

7.0.3 Procedure

In every session a group of four children tested the final prototype, each on one side of the pyramid with an individual tablet. It is important to note that this setup is a simulation of the ideal circumstances in the museum. Before playing the game, the participants were individually questioned about the existence of prior knowledge with regard to the pyramids. Once the game was completed, the children were once again interviewed individually with questions with the focus on the usability, educational and entertaining aspect of the game experience.

For the educational aspect of the interview, the participants were prompted to recall what they still remember from the game. The mentioned elements of their answers were ranked in order of occurrences, regardless of the correctness of the answer. This ranking was subsequently used to evaluate the recall of the different facts in the game. Furthermore, remaining questions were asked, which covered the learnable elements that the participant did not manage to mention by themselves. This allowed for a ranking to be made to evaluate whether the participants were also able to remember the correct facts through recognition.

Finally, the participants were questioned on what else they would like to learn about the plateau of Giza, and which of the topics of the other games (boat journey, mummification, and discovery of the tomb) they would be interested in. These answers were used to gauge the interest for a full realisation of the concept.

7.0.4 Materials

The results are evaluated using recall and recognition. During each test the user was asked the **recall** question: "What have you learned through the game? Are you able to tell anything about it?" The answers were scored in the order of how the elements were mentioned by the participant, regardless of the correctness of the answer (Table 5). The first element mentioned was scored with 4 points, the second with 3 points, the third with 2 points, and the last with 1 point. This scoring system resulted from the observation that the maximum recall consisted 4 elements, as recalled by the participants. The questions were then ranked according to the points obtained from this scoring system.

Subsequently, the seven **recognition** questions were asked in the order of their appearance in the game. The right answers were scored 1 point, half right - half wrong were scored 0.5 points, while wrong answers were scored 0 points.

7.1 Results

7.1.1 Usability

The first Nielsen's heuristic "Visibility of system status", was tested with a question about the understanding of the progress of the game (see Appendix). The majority (11 out of the 16, Table 4) of the children stated that the process of the game was clear and that they were aware of the fact that every phase was a new part of the pyramid.

The second heuristic "Match between system and the real world" consisted of questions about the readability and the understandability of the text. Almost all the participants mentioned that they were able to read the texts. Only one participant stated that she had some difficulties due to the fact she was not a very experienced reader yet. While the text was readable, some participants had difficulties with words such as 'ambachtslieden (craftsmen)' and 'beitel (chisel)'. Even though they found these words difficult, they all stated that they understood what they had to do in the game: "Yes. Click on the answer which you think is how it was done in the past, and then you are able to learn something about how they did it in the past and how they build a pyramid."

The heuristic about "Consistency and standards" focuses on whether the application is according to similar standards for usage with tablets for better consistency, and thus is about whether participants are comfortable with the game while using a tablet. 10 out of the 16 participants said they had some difficulties to scan the pyramid. This is caused

due to scanning being too slow. Subsequently, the heuristic 'Error prevention' focuses on the ability for the user to make correct choices without errors in the first place, and this was also marked positively by 13 out of 16 participants. The heuristic 'Flexibility and efficiency of use', similarly focuses on the ease of use for the target group of young children. According to 14 participants, it was not too easy but also not too hard.

For the 'Aesthetic and minimalist design', none of the participants found that there was too much text in the game. A participant in particular stated: "I would not know how to play the game if there would be less text". The participants found the game enjoyable, and 15 out of the 16 were excited to play the game again. The remaining participant stated that they would not choose to play the game again, since they already knew the answers.

Additionally, for the heuristic 'Help users recognize, diagnose, and recover from errors', 15 out of the 16 participants stated that it was clear what they had to do when they chose the wrong answer: "Yes, than I would think again and than I could chose another one". The last heuristic is about "Help and documentation", and similarly 14 out of 16 of the participants found that no extra explanation was needed to understand the game.

The results of the interviews regarding the usability are tallied in table 4. The users who reacted positively towards the various interview questions, were noted as positive in the table for that specific heuristic. Several heuristics consist of more than one question, and therefore the average of these outcomes are calculated and rounded off to an even number, if applicable.

7.1.2 Learnability

The question that scored highest on recall was question 4: "What kind of stones were used to build the pyramid?". Question 5:"Which tools were used to carve out the stones" scored the highest on recognition, meaning it was answered correctly more than any of the other questions.

8. DISCUSSION

8.1 Usability

There were several issues with the current game, which still need improvement. In the first place, the heuristic of 'Consistency and standards' scored slightly lower than expected, due to issues with the scan feature. This is a software constraint and might be solved by using more advanced software. This also highlighted the importance for good lighting in the museum.

While some of the participants skipped or quickly skimmed through the textual instructions, they still understood the concept of the game. On the other hand, other texts within the game were not mentioned to be too extensive. A possible solution is therefore to replace textual instructions with other forms of media such as videos.

Regarding the visibility of the system's status, the results showed a slightly lower score for usability. This was however not reflected in the observations, wherein none of the participants showed to have problems with understanding of the symbolization of the pyramid in 3 layers as a development process. A possible explanation for this phenomena would be due to the unclear formulation of the term 'status' in the interview question.

All in all, all children found the game entertaining and most children were willing to play the game again. According to the participants, the game introduced a novel yet entertaining way of learning which was much appreciated.

8.2 Learnability

The interview results of the final testing has shown that the children were more successful in recalling certain elements through augmented gameplay, than the recognition of specific facts that were mentioned in the textual explanations within the game without augmented scenes. For example, none of the children were able to answer question 7 (Table 5) and similar results were given for question 1 and 2, wherein the answers were only provided through the textual description of the game. This gives an indication that gameplay with augmented reality is more effective in transferring knowledge as cues than through passive reading.

Subsequently, the recall and recognition seemed to be better when similar elements were repeated. For example, question 4 and 6 had both a high recall and high recognition rate. A possible explanation for this increase in learnability could be attributed to the fact that the choices of stones were shown twice during the game. This is also supported by the model of memory (See 2.3), which confirms that rehearsal could help refresh the content and thus indeed improve the memory of the facts.

The choice of words used in the text also had an influence on the recall. The children, for example, also had difficulties remembering longer words such as "ambachtslieden (craftsmen)" and "piramidion (pyramidion/the capstone of the pyramid)". This shows that the used vocabulary could also negatively impact the recall of certain elements, especially with a target group of young children.

In addition, the rankings in Table 5 show that higher recall and recognition were better for the elements that were shown in the middle of the entire gameplay. In contrast, recall and recognition for both the first two questions (question 1 and 2) and the last question (question 7) were evidently lower. This gives an indication that the sequence of elements shown in the game also could have an influence on the learnability. However, it must be noted that these three questions were incidentally the questions that included non-augmented textual facts. It is therefore not entirely possible to conclude whether the sequence indeed have a huge impact on the learnability.

8.3 Group Interaction

One possible discussion point to be mentioned is the player's interaction with each other. Another possible aspect for research would be to analyse whether group interaction can improve the engagement and learnability through evoking competitiveness. This could be tested through implementation of a scoring board which allows the players to compare scores by themselves. However, not every child might be open for a conversation during a museum visit. The choice to increase group interaction would therefore required a balance trade-off.

8.4 Learning Opportunities

Another possible point for discussion is the one-sidedness of the educational aspect. The facts as provided by the

Table 4: Results Heuristics

Heuristic's topic	Average of user's outcomes (n = 16)	
	Positive	Negative
Visibility of system status (1 question)	11	5
Match between system and the real world (4 questions)	1	1
Consistency and standards (1 question)	10	6
Error prevention (1 question)	13	3
Flexibility and efficiency of use (2 questions)	14	2
Aesthetic and minimalist design (13 questions)	15 (14,67)	1 (1,33)
Help users recognize, diagnose, and recover from errors (1 question)	15	1
Help and documentation (1 question)	14	2

Table 5: Results Recall & Recognition

Question	Recall		Recognition	
	Total number of recall points (regardless of correctness)	Total number of recall points (regardless of correctness)	Total number of recognition points for correct answers	Ranking per question according to recognition points (1-7)
1. How long does it normally take to build a pyramid?	4	5	7	5
2. What is the most suitable place to build the pyramid of Giza?	2	6	5	6
3. Who built the pyramids?	24	3	12	2
4. What kind of stones were used to build the pyramid?	41	1	7,5	4
5. Which tools were used to carve out the stones?	11	4	14	1
6. How were the stones brought to the pyramid?	28	2	11,5	3
7. What had to be towed to the top of the pyramid?	0	7	0	7

game represents only how a pyramid is built in a simplified manner. The augmented game, on the other hand, also provides the opportunity to teach children about more aspects of the Giza pyramids then just the building process. Therefore a subject open for discussion could be that the systems prototype does not fulfil the full potential for knowledge transfer.

8.5 Testing Conditions

The prototype as proposed by this paper is designed to be played simultaneously by multiple players. With the final testing the perfect context was created: the amount of children present in the room at the same was equal to the amount of tables available (4 tablets one on each side). In the real context, however, more noise and people could have an influence on the learnability and engagement with the model. More research is therefore needed in a more realistic situation for more accurate validation of the usability and learnability.

9. CONCLUSION

The final product is an entirely playable game with augmented scenes. The aim was to enable an educational and entertaining experience tailored to the model of the plateau of Giza. Of interest for the museum is the appeal

the systems displays on children visiting the exhibition. The results of the final test showed that children find the game entertaining and that most children would want to play the game again. Another important point for the museum was that the system would be able to transfer knowledge. The final test has indicated that children were indeed able to learn and remember new facts about the building process of the pyramids of Giza through gameplay, especially when compared to the prior knowledge they possessed before. In short, the needs of the primary stakeholders, the museum direction as well as museum visitors, were met in this interactive design project.

10. FUTURE WORK

10.1 Ranking of the results

Future work would be to add a ranking of the achieved scores to encourage interaction between the multiple players. In order to make a ranking possible, the scores should be stored in a database. For this purpose a server is needed. This would enable the storage of a scoring board that could be reset daily with the purpose to keep the scoring board interesting for museum visitors. Ranking of the scores could be of added value in enabling human to human interaction among the different players.

10.2 Adaptability to the level of difficulty

The game does not take the age and level of knowledge of the user in consideration. However, it could be that the interaction between user and system could be further improved when the system is able to adapt the level of difficulty to the knowledge degree of the user. The effectiveness of this approach could be tested with A/B testing, and compared with the first game. Adaptability would provide the young museum visitors with more personal learning opportunities.

10.3 Implementation and validation of more games

While this paper primarily focused on the building pyramids game, multiple games were also introduced as part of the concept. A future work would be to implement the other games, which cover other factual processes regarding the Ancient Egyptian history. These games could be tested with A/B testing, and compared with the first game to more effectively validate whether learnability could be increased.

10.4 Testing Conditions

For future work an evaluation of this research in less than perfect circumstances would be of added value, since the real life circumstances in the museum will not be perfect. The museum will likely face the circumstances wherein there are more children visiting the plateau of Giza than the number of available tablets. A more realistic user test with inclusion of a busy environment and with more children than available tablets, would give insights into how the system would function in the real context.

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APPENDIX