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THE SCIENCE MUSEUM OF THE UNIVERSITY OF COIMBRA: A PLAYFUL EXPERIENCE

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A new way to explore the Physics Cabinet

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Abstract

How can we promote the autonomous visit and discovery of an already existing permanent exhibit without modifying it? The current project, "Science Museum of the University of Coimbra: a playful experience", associates cultural heritage and technology to enrich the experience of the visitor of one of the Museum's historical collection, the Physics Cabinet. Constructed as a game, the product designed in the frame of the project leads the visitor through the two rooms and engages him/her in finding information and establishing connections between the scientific instruments on display.

Keywords

1.   Introduction

Our first contact with the Physics Cabinet of the Science Museum of the University of Coimbra was made as a simple user and visitor. We can say that we missed out on a great opportunity by not being able to unscramble the messages beyond the scientific instruments. It is only when exchanging with experts that we understood the importance of the Physics Cabinet and its collection. When facing the problem of having such a rich cultural heritage and not being able to understand it by ourselves, we then thought that we could define of a new way to explore the Physics Cabinet.

The "Science Museum of the University of Coimbra: a playful experience" project consists of the design of an interactive multimedia product that allows the Museum's visitors to discover more information about the objects on display in the Physics Cabinet. From an experience adapted to mobile phones, smartphones and tablets, the developed product will expand the frame, i.e. the physical space of the

cabinet, thanks to the virtual space, and turn the visit to the permanent exhibit into a personalized and unique moment.

The product to be designed in this project aims to provide an independent and flexible visit the Physics Cabinet, without intending to replace the role of a "classic" guide. This is an alternative to the audience at the Museum. The experience becomes the organising element of the visit and an instigator for knowledge. The technology in this case is an asset: when putting objects and instruments from the collection of the Physics Cabinet to "talk" and interact with people, the experience will affect them differently. The product invests in learning and in education through fun animations that contain rigorous scientific contents.

The final goal of the project is to provide to the Science Museum a well differentiated offering, focusing on the specifics of the Physics Cabinet, an important place in the history of science in Portugal and at an international level.

This report shows how we investigated on the several items gathered at the Physics Cabinet to deepen our knowledge of the collection, how we examined the different new models used in museums to present their exhibits, as well as the several steps we undertook to define the concept and the design of our product, the outcomes of the process and the conclusions made after the prototyping and playtesting phases. The design review and evaluation finally lead us to our concluding remarks and future perspectives.

2.   State of the art

To be able to design such a product for the Physics Cabinet of the Science Museum of the University of Coimbra, we will reflect first on the evolution of the multimedia tools created for museums (Mathey, Economou) and on the importance and implications of a virtual world for a museum exhibit (Perrot, Belaën, Roussou). Some concrete examples of innovative approaches will be presented (Belaën, Ballagas).

On a second step, we will focus on the relation between games and learning processes and make a link with the playful experience we aim to provide and its goals (Gee). The concepts of interaction and immersion (Belaën), as well as the ideas of narratives and hypermedia navigation (Ryan, Varano) will be analysed to construct a theoretical basis to the project.

Finally, some topics related to game design (Koster, Pereira and Roque) and to mobile learning (Wake, Benford, Fosh) will be discussed before we present the prototyping phase of the product. Those ideas will be used namely to shape the experience structure.

2.1 A Panorama of Museums Applications

The museums' exhibits changed in the last 30 years with the evolution of the information technology. For Belaën, we note an increasing sophistication of interactive museum devices to compensate for the trivialization of technical objects.

"Faire marcher des ordinateurs ne constitue certes plus une motivation en soi pour aller dans des expositions à caractère scientifique et technique, et on assiste à une volonté de sophistication croissante des dispositifs muséographiques interactifs pour compenser la banalisation des objets techniques dérivés de la micro-informatique domestique" (Belaën, 2003).

As we have increasingly sophisticated tools at home, we expect increasingly sophisticated tools also in museums. How did this phenomenon affect the museology and the exhibitions up to now?

A constant evolution

We may first wonder "Why are museums so interested in the IT?". Xavier Perrot believes that "*in the field of museums, virtual reality is intended to be a means to display collections in a designed world. VR sets you free of real world material problems such as distance, time and space. (...) Museums can find in computer-based applications very good tools to stress their entertaining and educational purposes*". In 1993, Perrot already makes a list of "classical" multimedia applications we can expect in museums:

- simulation of real phenomena;
- experience of virtual world or artefacts;
- diffusion of audiovisual content;
- location and directories of the artefacts and the exhibitions;
- orientation in the museum;
- related documentation to the collection;
- quiz, games and learning activities (Perrot, 1993).

The virtual reality and those several solutions are also interesting for our playful experience as it may enable us to interconnect objects, stories, ideas and concepts. We indeed assisted in the last decades to the creation of several tools for museums. Aude Mathey makes a good summary of the evolution of the museums applications in her essay on the "virtual museum" which completes the first description given by Perrot. For her, the devices designed for museums went from a virtual duplication (e.g. 3D visits), to interactive tools (e.g. computer kiosks), immersion devices (eg.CD-ROMs), podcasting, augmented-reality, and finally apps (Mathey, 2011).

Economou is in 1998 one of the first presenting the results of a research study which examined the effectiveness of a multimedia application created for an exhibition interpretation (a computer kiosk). One of her main conclusion is that linear and non-linear ways of thinking and exploring the exhibit are essentially connected to the age range of the visitors. But we may wonder if those conclusions would still be valid today, as people are used to direct their reading as a navigation, to "surf" on the Web. Visitors wouldn't be more attracted today if we challenge them through a non-linear path? Still according to Economou, multimedia could be an auxiliary to present data and convey content.

> *"The free association of data through a computer screen can potentially assist in a synthesis of cultural puzzles, and the construction of a holistic picture from rudimentary fragments of information"* (Economou, 1998).

The computer programme encouraged visitors to explore and engage with the rest of the exhibits, refers also Economou. Those two last aspects are important for us, as the Physics Cabinet is only a part of the Science Museum assets.

Towards a spatial knowledge

For Belaën, the science museums were among the first to use those new IT possibilities to share their concepts, responding to a trend of a "Museology of ideas" which lies beyond the merely presentation of authentic objects.

> *"Les musées des sciences ont été précurseurs dans l'utilisation de ce genre d'outils expographiques car ils offraient la possibilité d'exposer des concepts, des idées, au-delà de la mise en exposition de l'objet authentique"* (Belaën, 2011).

We share the opinion that IT solutions may extend the experience of the visitors discovering a science museum. To illustrate this idea, we can refer the example given by Maria Roussou in her article on learning, play and interactivity, about the series of interactive exercises called "*EUREKA!!! Stories from Archimedes*" and developed to complement an exhibition on ancient Greek mathematics. The researcher points out how interactive virtual experiments made visitors of all ages come to understand some of the most famous of Archimedes' discoveries (Roussou, 2004).

In parallel, Mathey notes an evolution in the concepts of the museum studies, which evolved from education to participation and collaboration. Nowadays the museum applications usually mix several of "classical" multimedia possibilities referred by Perrot to enhance the participation of the visitor, leading to new exhibits' concepts in museum studies and not always consensual ones, namely the "show-exhibition", the "journey exhibition" and the "simulation exhibition" as stated by Belaën.

"Chez différents auteurs, on trouve quelques tentatives pour différencier les expositions: « exposition-spectacle », « exposition-parcours », « exposition-simulation ». Mais les termes ne s'imposent ni chez les chercheurs, ni chez les visiteurs" (Belaën, 2004)*.*

This evolution is also visible in an example given by the researcher. Florence Belaën discusses and compares in one of her article two exhibits on climate change organised in Paris, one more "classical" with different multimedia products and another more "innovative" as it only gathers digital images. Before discussing the differences between the two approaches, her case study stresses that in both cases a particular time and space is created to engage the visitor (and "immerse" him/her in the second exhibit, as we will see later). That's what Belaën calls the "spatial knowledge" (Belaën, 2004).

To share their knowledge and follow their pedagogical goal, museums more often aim to create an experience when they organise an exhibit, thanks to a new mode of mediation. Museums now aim to proportionate intelligent environments, by providing to the visitor a memorable, novel and sensational experience, and strengthening the visitor complex feeling of living in a particular "space and time" and have the chance to "be there at that time" to connect with a spatial knowledge (Belaën, 2011).

As our first part of the state of the art and the few examples above show, it is crucial for museums to focus on the visit experience, not for the experience by itself, but to show the importance of the objects there and the knowledge behind them (Belaën, 2003). We will now consider what can enhance a visit of an exhibit and makes it become outstanding. We will first ask the following question: how can we make the visitor interact with the exhibition so that he feels part of the story? The second question will be connected to the knowledge itself: how can we transmit ideas and concepts in a pleasant way? Another angle for our approach will be about mixing playfulness and information. We will analyse the concept of learning games as a way to aggregate both in a single experience.

2.2 Interaction and Immersion

With the evolution of the IT solutions, several studies have been conducted on interaction and interactivity as a way to get the visitor involved. As a starting point, we will refer to Mathey's reflection when she asks in her book what is interactivity and interaction for multimedia. She proposes 4 levels of interaction that we may consider for our project (Mathey, 2011):

- the user reaches the web editor
- the user participates to the content (e.g. videogames)
- the user can create contents that are controlled by the web editor
- the user is a co-author

For this last aspect, Mathey goes in the same direction that Xavier Perrot, who defends that "*one big breakthrough of multimedia is that its content has often to be created by several authors, and that the user might also become an author by providing content or changing it*" (Perrot, 1993).

And what could and should be interactivity for a museum? After analysing the interactivity of several virtual reality interfaces and applications for museums, Maria Roussou concludes in her paper that "*interactivity in a museum VR exhibit has the challenge of preserving a balance among the following: accuracy, educational efficacy, high motivational and engagement levels, quality visitor experience, and seamless, natural, and customized modes of interaction*". For her, the experience must be designed to "*encourage the visitors to question what they experience and to engage in contradiction, confusion and multiplicity of representations inherent in the*

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display of museum content, while at the same time avoiding the danger of a confusing and fragmented experiences" (Roussou, 2004).

The interactivity is also something crucial for games and omnipresent in videogames. For example, in the description of their project, Ballagas and Walz refer that the detector of REXplorer has artificial intelligence and is able to talk directly to the players and they believe that "*this makes the device a character in the game, encouraging players to anthropomorphically relate to it as a team member helping them achieve their goals*" (Ballagas and Walz, 2007).

But in my view, games - and also museums as we are going to see below - go beyond interactivity and offer an immersive engagement to their players/visitors. Players/visitors become part of the story to be told. In her book, Ryan evokes three types of immersion – the spatial, temporal and emotional immersions – and also three types of theatre stage design where interactivity, participation, involvement and immersion are clearly enhanced (Ryan, 2001). The figure below (Figure 1 – Ryan's proposal to reconcile Interaction and Immersion) may inspire us for the concept proposal of our project:
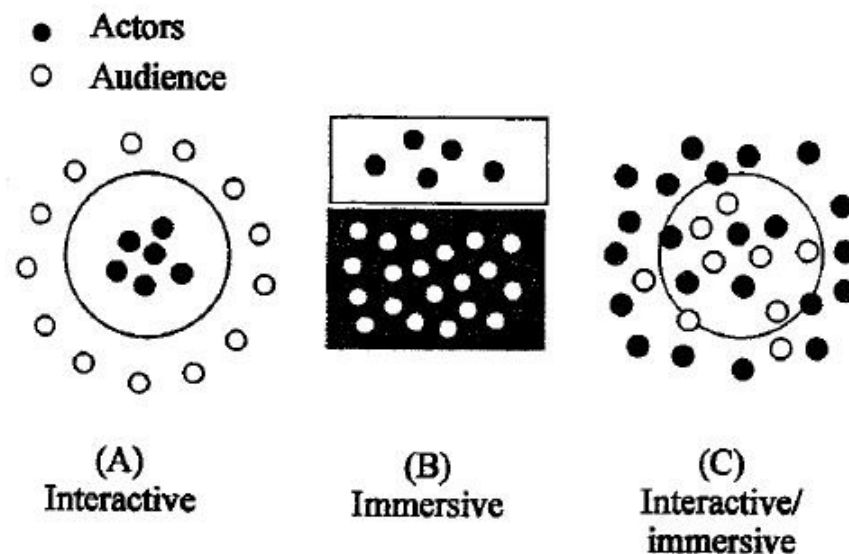
FIGURE 14 | Three types of stage design

Figure 1 – Ryan's proposal to reconcile Interaction and Immersion (Ryan, 2001)

For Belaën, "*museums are increasingly employing techniques of immersion in order to stimulate an emotional response in the visitor*" (Belaën, 2005). For this, they first work on the reference world of the exhibit, which (1) existed and may be reproduced correctly; (2) doesn´t exist and has to be created or (3) existed but

museums don't want to reproduce it in details and mix the two approaches to let space for the interpretation of the visitor (Belaën, 2003) to create an universe.

"Après avoir analysé plusieurs dispositifs que l'on peut qualifier d'immersifs dans un musée des sciences, nous sommes parvenus au constat que le discours scientifique servant de référence était rendu sous forme d'« univers ». Le propos exposé donne naissance à un espace-temps que le visiteur est invité à traverser. Cette spatialisation de la connaissance apparaît comme un moyen de « plonger » le visiteur dans le propos" (Belaën, 2004)*.*

An exhibit presented by Florence Belaën in 2005, about the Titanic, gives us food for thought, considering its mix of several immersion techniques. In her study, the interviewed visitors enhance the efficiency of the scenario and its "stage set" with real objects of the boat and references to real elements to make them believe that they really entered the Titanic.

"Leurs propos mettent l'accent sur l'efficacité de la combinaison de plusieurs techniques d'immersion, celle de l'identification à un personnage mi-réel, mi-fictif, l'histoire du Titanic mise en scène par le parcours, et enfin la possibilité de revoir les lieux, de déambuler comme sur une scène. Mais au-delà des qualités du dispositif qui participent à l'illusion, le sujet et la structure du scénario facilitent également l'entrée du visiteur dans l'histoire racontée" (Belaën, 2005)*.*

Beyond the set of the exhibit itself, that's the story behind the exhibit which makes the visitors partake the experience.

The interactivity and the more frequent immersive aspect of the exhibits make us wonder if the visit shouldn't be then compared to a game and constructed as a game. Both are able to deeply absorb the participant, in both cases the participant has to accept the rules, we play with space and time and have a disruptive experience regarding to daily life ("ubiquity myth") in both cases. Florence Belaën is the one highlighting the constant comes and goes between dream and reality, between ratio and emotion in both cases, even if she is really critical on the possible effects of an immersive approach for a scientific exhibition and its discourse (Belaën, 2005). Ryan meanwhile invokes entertainment Virtual Reality, computer games and MOOs (MultiUsersDomain object-oriented, i.e. a text-based online virtual reality system to which multiple users/players are connected at the same time) as a potential reconciliation or marriage of interactivity and immersion.

Despite the warning of Belaën, when she advises not assimilate the experience in the museum to any other experience in an amusement or theme park or from a videogame, we believe that videogames, and namely the so called serious games, may indeed be useful for our playful experience to implement an immersive interactivity.

2.3 Design of Learning Games

The similarities between immersive exhibitions and games led us to consider learning games as a serious potential way to design a new offer for the Physics Cabinet. But why do we wish use the videogames example to our project? We do because several of their specifications seem particularly interesting, as Gee refers in his work on learning games:

- "Video games are act and goal directed preparations for, and simulations of, embodied experiences"(Gee, 2007b);
- Gamers are an "insider" to the game, a teacher and a producer and not merely a consumer (Gee, 2007a);
- "[Good video games] show that pleasure and emotional involvement are central to thinking and learning" (Gee, 2007b);
- Video games incorporate good learning principles. James Paul Gee enumerates 36 principles in total that we will explore for our prototype (Gee, 2007a);
- "Games are problem-solving spaces that create deep learning", as they induce an engaged learning.(Gee, 2007b)

Those elements remind us several of the concepts we discussed above, as the immersive experience, the active role of the player/visitor, the importance of the playfulness (Ballagas and Walz), the identity and identification as a learning principle (Belaën), etc. For Pereira and Roque, serious games are games with learning purposes, with characteristics that make videogames powerful contexts for learning: to include different key elements of learning, to be engaging, to allow experimentation with and compare several perspectives, to support various types of representations, to be themed to provide contextualized learning (Pereira and Roque, 2009).

For the playful experience, we may then get inspired by the general field of technology-enhanced learning (TEL). In fact, our project comes close to a location-

based gameplay which offers a real mobility to the player: the REXplorer. REXplorer is a pervasive game that helps tourists to explore the history of Regensburg, Germany. The nature of the game is to reproduce the interactive nature of videogames and their consequent ability to captivate and engage their audience. In their report about the REXplorer experience, Rafael Ballagas and Steffen P. Walz emphasize the importance of the playfulness to communicate contents.

"By the way of the iterative design techniques, we were able to find an appropriate balance of fun and seriousness, blending fact and fiction in a way that conveyed historical information effectively, yet preserved the engaging techno-magic background" (Ballagas and Walz, 2007).

This approach rejoins the objective of an interactive playful experience in the Science Museum of the University of Coimbra.

The videogames characteristics that promote learning fit particularly well the learning purposes of sciences. Gee himself refers several times the connections and similarities between games and sciences. He opens up the frame of the learning games to a dimension which we think is important for our project.

"'Game-like learning' need not involve an actual game – it simply requires learners to live and have (guided) experiences in the world from the perspective of the area being learned, for example, a particular branch of sciences. But actual videogames hold out great potential to enhance and deepen this process – to offer learners a myriad of new experiences that can allow them to learn situated meanings and not just verbal definitions" (Gee, 2007b).

He advocates for an effective human thinking and learning thanks to videogames and playful experiences.

"Effective thinking is about perceiving the world such that the human actor sees how the world, at a specific time and place (as it is given, but also modifiable), can afford the opportunity for actions that will lead to a successful accomplishment of the actors' goals" (Gee, 2007b).

For Gee, to adopt the identity of a scientist means adopt a set of values, attitudes and actions. That's this "being-doing a scientist" that will lead to deep learning.

"While commercial games often stress a match between worlds and characters like soldiers or thieves, there is no reason why other games could not let

players experience such a match between the world and the way a particular type of scientist, for instance, sees and acts on the world. Such games would involve facing the sort of problems and challenges that type of scientist does and living and playing by the rules that type of scientist uses. Winning would just mean what it does to a scientist: feeling a sense of accomplishment through the production of knowledge to solve deep problems" (Gee, 2007b).

But how do we make the visitors live and have (guided) experiences in the Physics Cabinet? How do we construct such an experience? We will now deepen our reflection on the creation of an effective playful experience by following and analysing two paths suggested by the literature: the iterative and narrative techniques and the game design techniques.

2.4 Narratives

In my opinion, Perrot's words are the best to highlight the importance of narratives for an immersive experience that we can apply both to a videogame and an exhibition. He writes already in 1993 that "*to enhance the visitors experience and to improve the museum educational role we must not forget the narrative dimension. We have to rediscover in the digital world the power of storytelling antique myths which are still a successful mean of knowledge transmission*" (Perrot, 1993). Maria Roussou also enhances an "embedded sense of narrative" as a main characteristic of the learning experiments she presents in her article. For her, the sense of narrative is sometimes literal and obvious but also often "*implied in the interaction with the virtual environment and in the completion of tasks with a concrete goal*" (Roussou, 2004). Her thinking will lead us to define the narrative we imagine for our project.

Dramatization and identification

As we saw with the exhibit on the Titanic presented by Belaën, there is more and more a dramatization of the message due to the immersion. In the multimedia applications for museums, there is a role to be adopted by the visitor: through the sensation he has got but also through the role he plays in the dramatization itself. Florence Belaën refers that the narrative system is crucial to the immersion of the visitor.

"Le système narratif porté par le scénario de l'exposition participe également à l'effet d'immersion recherché. En effet, l'illusion est d'autant plus forte que le visiteur a l'impression d'être impliqué dans le déroulement du scénario proposé" (Belaën, 2005).

Several writing techniques will support the immersion (which are also used in videogames), like the creation of characters as substitute to actors in a play, the use of the first person of plural and the direct speech ("Let's do that"), the different focalizations and some identification techniques, as for example the use for the exhibit on the Titanic's story of a boarding pass issued to the name of a real passenger of the boat. Belaën defends that an explicit device of identification to a character also produces a catalyst in the search for an effect of immersion.

Narrative and interactivity

We saw earlier that interactivity is a crucial element for the experience to be designed. At first, we may think that the traditional narratives don't allow any kind of interactivity yet. When we think about textual narratives for example, we indeed think about a fixed sequence of events and elements that lead to the epilogue of our story, in a linear way. But let's look for alternatives. For example, in his PhD thesis, Varano brings closer stories and games, narrative and interactivity, by referring the typologies used by Julien Favre and Sébastien Genvo to describe what they call "interactive narratives" and "game narratives" (Varano, 2010):

- interruptive narrative: the story stops by the time the player takes a decision;
- topographic narrative: the access to certain spaces and/or solving a puzzle unlock a passage to another space;
- self-generative narrative: total freedom of the player who constructs his story
- multimodal narrative: several media tell the story and interact on a homogeneous content;
- multifocused narrative: to navigate between different views, subjective vision (omniscient player) or external vision.

Linear and non-linear approaches

For Varano, the links between games and stories are now refreshed thanks to the hypermedia fiction and electronic literature that create a non-linear medium of information. In a non-linear fiction, we delegate to the reader/user/player part of the story and create an open world where the user can choose the order of his steps or even solve puzzles parallel to the main story. For our project we may consider a mix of sequences, parallel paths and embedded steps to enrich the experience.

In her book, Marie-Laure Ryan goes further in her reflection by assimilating non-linear modes of reading to the hypertexts we all know thanks to the Internet navigation, the "point-and-click interactivity". People are now used to jump from one node to another, from one "lexias" to another, as Ryan refers for her textual analysis. This is pure interactivity. But the segments and the links created also gain importance by constructing a story, a narrative. From this observation – the non-linear reading experience composed as a mosaic structure - Ryan introduces several metaphors which represent the different writing options.

"Easily detectable relations between adjacent segments suggests the metaphors of travel or of the kaleidoscope, because they give meaning to sequence; links that break up semantic continuity tend to redirect the reader's focus of attention toward a global coherence to be reconstituted in jigsaw-puzzle fashion; and relatively autonomous lexias will promote the shopping-cart scheme" (Ryan, 2001)*.*

From these different options, Ryan points out several structures of interactive narrativity (Figure 2 – Networks and interactive narrativity (Ryan, 2001)) which alternatively enhance more the dramatic narrative or the interactive environment. We will retain four of them as inspiring for our playful experience, with their bidirectional segments, their main nodes and alternatives proposed.

2.5 Game Design and Cultural Heritage

The creation of a project connected to a cultural heritage and to historical facts implies an increased attention to details and has a strong impact in terms of learning and knowledge to be transmitted. Roussou's warning about the authenticity of museums particularly echoes in our reflection.
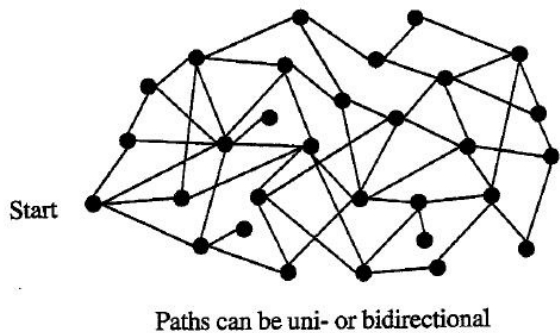
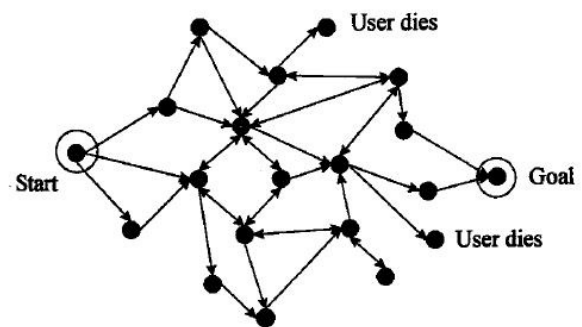FIGURE 5 | The network: A hypertext-style decision map allowing circuits

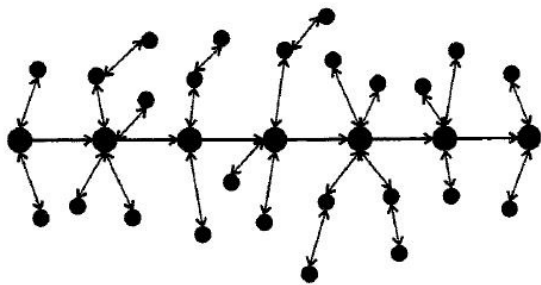FIGURE 8 | The maze: Structure of an adventure game
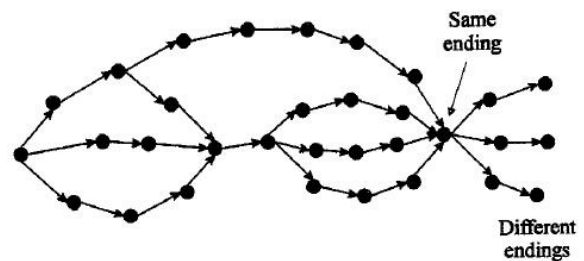
FIGURE 7 | The vector with side branches

FIGURE 9 | The directed network, or flow chart

Figure 2 – Networks and interactive narrativity (Ryan, 2001)

"Museums 'tell stories' through the collection, informed selection and meaningful display of artefacts. (...) Authenticity is both an effect that exhibit makers strive to achieve and an experience that audiences come to expect from museums. It is crucial for museums to preserve this context of knowledge and credibility while providing memorable experiences that keep visitors coming back" (Roussou, 2004).

So how can we simultaneously promote, and above all, design fun and credible cultural experiments?

Toward an effective gameplay

First of all, what makes a game unique? We find some clues on how to answer this question in the work of Jan H.G. Klabbers.

"Strongly related to the play element of culture is the notion that games - as forms of play – are expressions of human and social systems that generate culture. If play is valued for itself, it can only intrinsically be valued, if it creates a human and social system that temporarily is a world of its own. What will happen within the magic circle is both real and imagined. To be able to interconnect both worlds, we need a suitable core concept." (Klabbers, 2009)

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We will also note his reference to Thavikulwat when he writes that "computer-directed simulations" (i.e. projects close to our project) are solutions where games became "functional to a goal outside the immediate sphere of play". We are going to reflect later on the goals of our playful experience because they conduct our whole design concept. For Klabbers, games should also enclose a mix of "foci of interest", from learning and education to individual competency and cross-cultural communication. We already mentioned those several elements above, when we discussed about serious and learning games as well as immersive interactivity[1].

In his article called "From Interaction to Trajectories: Designing Coherent Journeys through User Experiences", Steve Benford stresses for his part that spatial structures, temporal structures, the variety of performance roles and the computer interfaces are important for the structure of interactive user experiences (Benford et al., 2009).

As a first step, we will complete those four key facets that combine together and the basic ingredients of game architecture mentioned by Klabbers – ingredients that appear at the intersection of the actors, rules and resources of a game with its syntax, semantics and pragmatics – by using the game design field and studies to find general guiding principles to create an effective playful learning experience. We will, for example, try to transform the advices given by Gee into concrete solutions:

- "[games] are good if, as player, you begin to **think and act like a game designer** while you play the game";
- games acts are **open to player choice** and are different for different players;
- gamers need to **feel control, agency, meaningfulness, expertise** when facing risk and complexity;
- the games distribute knowledge and skills through smart tools (performance before competence) and distribute elements earlier in the game so that they will be used later for complex problems (i.e. The "**distributed knowledge**" feature) (Gee, 2007).

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1 I would like to emphasize at this point that with this project, we go beyond the usual restrictions of digital games reported by Klabbers. The visitor will interact with a virtual world, but he/she will also enter a new physical one. We are enhancing the human experience through direct face-to-face interactions, where we mix reality and technology.

For our project, we will also keep in mind some of the game design guidelines given by Pereira and Roque:

- The game model should be **representative of the real phenomenon** (realism is one of the characteristics of games that capture player's attention);

- The challenge in the game will be influenced by the **complexity of the model** (learn vs. get bored vs. game too complex and obscure);

- The **game model should be balanced** in view of the target audience and scenario of use;

- The **representations** in the interface should therefore be **consistent** with the game model and revealing of the game state, to enable the player to build a sense of understanding. It means that the representations must have a clear and consistent purpose to make the player have the correct idea;

- The **feedback to the player should be appropriate, guiding and significant**. For example, this is important to create stages in the game to allow feedback in the game to influence the construction of the player strategies and to help him to decide on the next actions;

- The actions modelled in the game should be significant in the modelled **context** (Pereira and Roque, 2009).

Now that we defined a basic framework for our playful experience, we will focus on the utilization of games in a cultural context.

A cultural context for an individualized exploration

As a second step, we will look how the specificity of cultural heritage may influence the experience design. For this, we will look at Jo Dugstad Wake's work, from the University of Bergen, Norway. In his PhD thesis, the researcher gives a few hints and tips about mobile location-based games and their relation with learning, by presenting the concepts of Mobile Learning (ML) and Technology-Enhanced Learning (TEL) that we discussed also with REXplorer experience.

According to Wake and the several authors he refers to, the widespread introduction of mobile devices and mobile use practices changed the learning process which became a tool mediated and cultural-historical activity. Wake

discusses the operationalisability of the new devices, the importance of the context and the "conversations" (exchanges) for learning as well as the appropriation of the contents by the learner/user/player and the evolution from a mass communication to an "individualised mobile mass communication". "*The process of appropriation is viewed as emergent; practice is central, and understood as the learner's engagement with a particular setting*", he refers. As a conclusion, Wake presents a contrasting theoretical perspective that emphasises the concept of practice, points out how design of artefacts must take the current use practices as a starting point, and how technological, institutional and pedagogical aspects relate to these practices.

"*The design of computer-based artefacts is directed towards a future use situation, but also entails taking the present practices as a starting point, as the need has arisen from their experiences*" (Wake, 2013)*.*

Addressing in particular the specificity of mobile location-based games, Wake shows how game players rely on their mobility in their interaction with the game and how the appearance and characteristics of different physical locations are part of the game constellation. Several issues such as the organisational and pedagogical factors mentioned above, must be considered in the design process.

The concept of "trajectories of interaction" is, on the other hand, emerging for the design of a cultural visiting experience. According to Benford, "*a trajectory describes a journey through a user experience, emphasizing its overall continuity and coherence*" (Benford et al., 2009). The researcher points out the fundamental tension between an author's ideal trajectory that is designed into an experience and a participant's actual trajectory, a tension that we may also be confronted to in our own experience.

Various notions have emerged from this first statement made by Benford, as the canonical trajectory, the participant trajectory and the historical trajectory, giving place to a new conceptual framework which may be useful for our location-based experience in the Physics Cabinet.

"*User experiences can be described in terms of three fundamental kinds of trajectory:* canonical trajectories *are created by authors to guide participants through an experience;* participant trajectories *describe each individual participant's personal journey through the experience and may diverge from and reconverge with canonical trajectories due to the respective "forces" or*

interactivity and orchestration; and historic trajectories*, that select and then represent recorded participant trajectories in order to provide a retrospective view of what happened in an experience* (Benford et al, 2011)*.*

In this last quote, a word specially gets our attention: *orchestration*. In the paper he writes in 2011, Benford presents the spectator interface of the interactive game "Day of the Figurines". It is particularly interesting to see how the artists and designers have worked on a multi-scale notion of interactional trajectories for the preparation of such an user experience in order to influence the spectator. They "*combined trajectories through individual displays, trajectories through a local ecology of displays, and trajectories through an entire experience*" (Benford et al., 2011). For our project, we will also keep in mind the detail of their design (designing the size, shape, height and materials of two tabletop interfaces before carefully arranging them in a local setting) and tips such as using small cute figurines to get an emotional engagement from the user, counting on the group effect to attract people or lowering the height of the tables to make the spectator bend over, take a closer look and then engage with the spectator interface.

Among the several notions discussed from Benford's reflection, we will emphasize in particular the importance of the key transitions; the relevance of both global and local trajectories as well as their complementarity and also the suitability of the several phases that a local trajectory may include (approach, engage, experience, disengage and reflect).

In the diagram below, Fosh et al. illustrate how their experience in a sculpture trail is phased according to the different moments of the interaction between the user and the object (a sculpture here). This approach looks promising, namely for our playful experience. We will for example retain the role that the music plays in the understanding of the stages (Figure 3 – The five stages of Fosh's local trajectories (Fosh et al., 2013).).

We are also going to reflect for the playful experience on the latest idea of "trajectories through interpretation" where official interpretation is given to the visitor only after his/her engagement.

"We suggest that trajectories through interpretation, moving back and forth between openness and closure and through multiple interpretations, may be suitable for many cultural experiences, especially ones that involve a didactic element such as museums and exhibitions" (Fosh et al., 2013)*.*
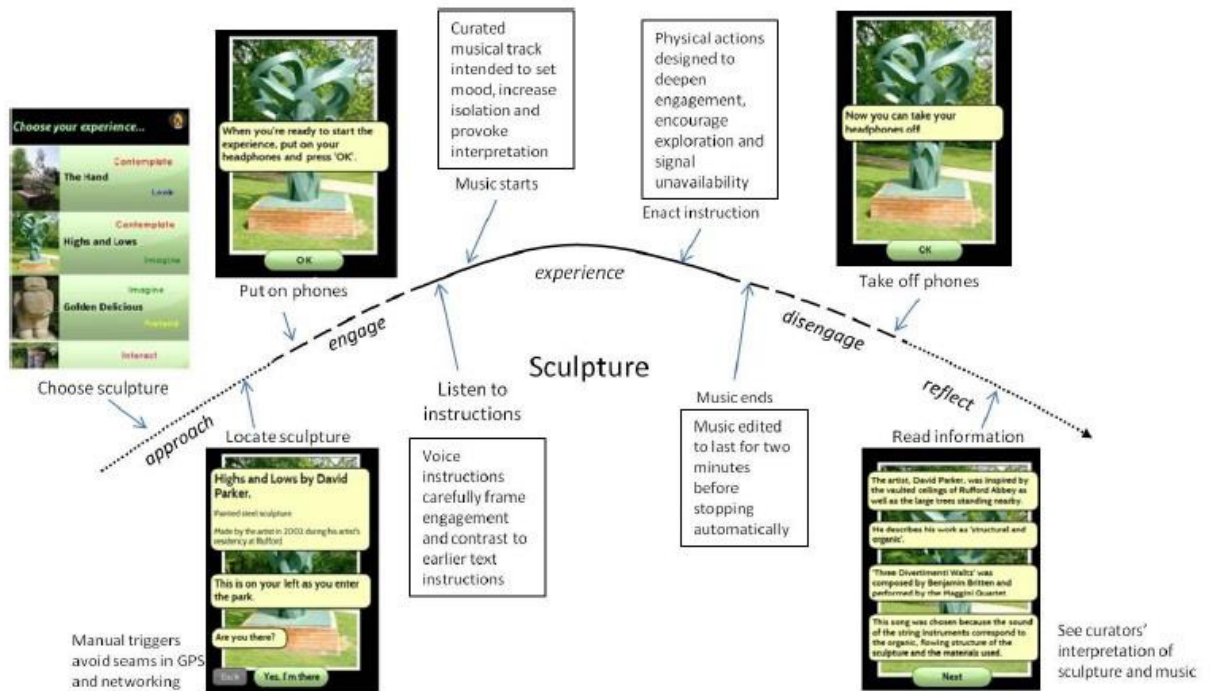
Figure 1. Design of the local trajectory through each sculpture

Figure 3 – The five stages of Fosh's local trajectories (Fosh et al., 2013).

Some more examples of location-based games and their design

Our "game" designed for the Physics Cabinet cannot be played anywhere and takes after some location-based games and pervasive games that are played in a specific town or part of a town and use specific visual characteristics of that place as part of the game design. From the several examples of location-based games given by Wake in his thesis, we may retain two, which are particularly elucidative.

We chose first *Mad City Mystery* (Squire & Jan, in Wake, 2009) because, similarly to the playful experience we want to introduce, the game:

- relies on text, documents and multimedia;
- states a role to the player since the beginning, an investigation;
- its players are acting as friends of the main character;
- the gameplay involves interviews with virtual characters;
- the educational purpose is tied to science learning, and in particular the development of scientific argumentation skills through the investigation;
- is designed so that there are several possible answers to the main challenge, to help students develop complex problem understanding.

Then Premierløitnant Bielke is a good example of the "philosophy" of quests a game designer may instil in a location-based game (Wake, 2009). The main idea behind the game called Premierløitnant Bielke is to combine the locations that were relevant for the production of gunboats in Sandviken, Bergen, with a storyline, or set of quests, about the same locations in the form of a game to potentially provide an immersive and novel way of learning history. The games mix intact locations, but also non-existent ones. Our goal would be to produce a novel way of learning science, but the path is the same and some of Wake's conclusions after his evaluation studies can guide our work. Wake concludes for example that a briefing session including a presentation of the historical context before the gaming session may be useful to the player (Wake, 2009). We believe that this aspect is also important to understand the historical context of the creation of the Physics Cabinet. He also enhances the discrepancy between the time-spent aspect (we aim that the player observe carefully the context he is evolving in) and the scoring system (which makes the player display a tendency to want to complete the game as fast as possible in order to win). We consider that it is worth it to think about this in our own design concept.

We found one more example in our literature review. In her work, Mathey refers to a project launched by a French company, *MobExplore* (Mathey, 2011), which somehow also corresponds to what we want to produce for the Physics Cabinet. *MobExplore* (www.mobexplore.com) proposes to museums or other cultural stakeholders to autonomously create an "interactive journey" and playful paths around their assets for smartphone. How does it work? At each step, the visitor is invited to perform an action: answer a question, take a picture, find an element from a detail revealed, leave a comment... Once the action is completed, the application gives him more information. Thanks to the interactivity the contents are gradually presented and respect the rhythm of the visitor who is more involved and is enabled to store more information. Each step may be completed by a media item (image, audio or video) that provides contextual elements about the objects or their authors. This unfolding of actions to captivate the audience seems interesting but we feel that something is missing to interconnect the several elements. What is leading the visitor to the next step as in Benford and Fosh trajectories? Let's deepen our reflection with Varano's theoretical framework.

2.6 A three layers design: places, actions and narration

As a result of the reflection undertaken so far about interactivity, immersion, cultural heritage, trajectories and location-based experience, we find Varano's process to define the structure of a playful and didactic experience in the frame of cultural heritage really interesting. In his PhD thesis, as a reinterpretation of the topographic and self-generative narratives of Favre and Genvo as well as of the linear approach of texts and the non-linear approach of hypertexts, Varano starts from the hypothesis that he has to establish a learning frame by overlapping a topographic route and a cognitive route to produce the product he is aiming for, i.e. to create a hypermedia learning route to help understand cultural heritage (Varano, 2010). This base structure is supposed to improve the learning by suggesting crossings for the information path and the knowledge path. On top of these two routes, Varano adds a third one, a "scripted" route (a scenario with clues and puzzles), which is supposed to build the links and connections between the learning units and allow the user to put sense in his experience.

By knowledge crossings, Varano understands points where the user can (re)invest the information he has been receiving on his "information path". Those points on the topographic route correspond to physical elements or items of the place to be explored, in our case, the Physics Cabinet. A pure hypertext structure could lead to the loss of the information, that's why Varano establishes those organised and sequenced spaces to help the reasoning of the user (Figure 4 – Crossing information and knowledge (Varano, 2010)).
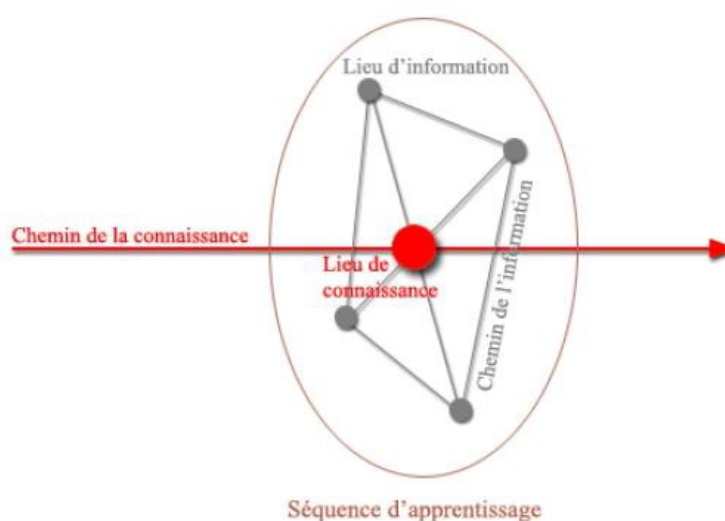

Figure 4 – Crossing information and knowledge (Varano, 2010)

The cognitive route corresponds to the nature of the information given on each crossings and the way the user will interact with it. Varano suggests a multimodal and an interactive approach to allow the appropriation of the contents by the user (Figure 5 – Multimodal approach of the cognitive path (Varano, 2010).).
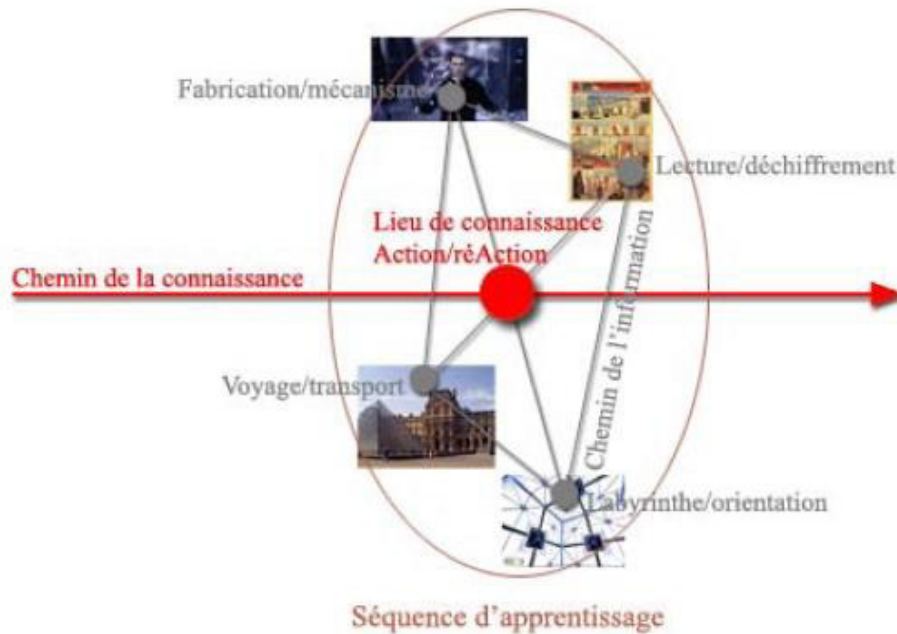

Figure 5 – Multimodal approach of the cognitive path (Varano, 2010).

The navigation on those two paths doesn't mean only to join two points but represents the need to join those two points. The knowledge crossing will lead the user to look for the information crossings and also constitutes the point where the user sums up the information and goes forward. From the learning unit ("Séquence d'apprentissage") presented above, Varano imagines several types of combination of those units, which correspond, for him, to levels of difficulty: a linear organisation, a non-linear organisation and two mixed ones (Figure 6 – The several combinations of learning units (Varano, 2010)., next page).
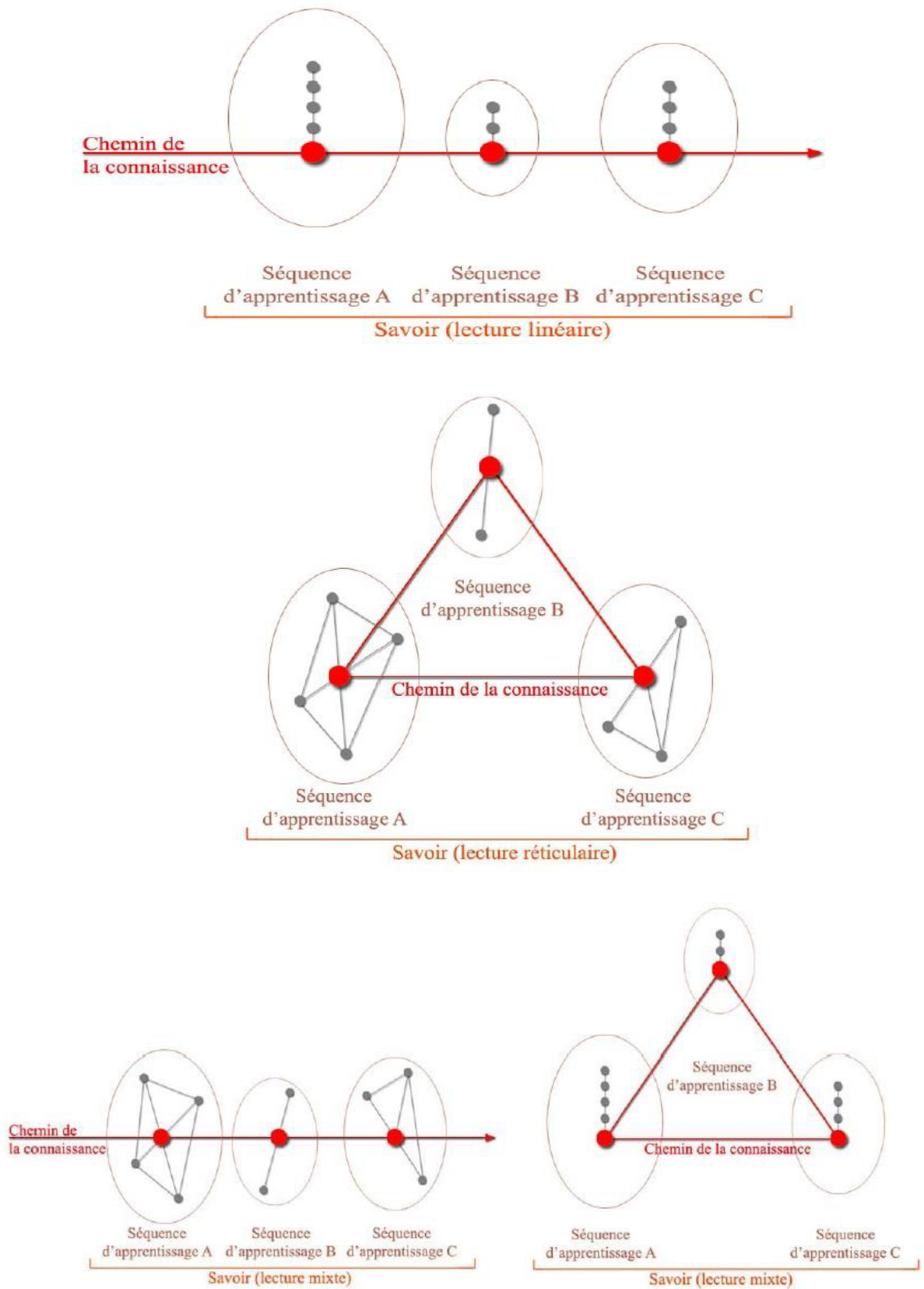
Figure 6 – The several combinations of learning units (Varano, 2010).

Varano advises not to mix the organisation to be consistent and coherent and not perturb the reasoning of the user. The possibility of shortcuts is however encouraged to motivate the user. They can exist in a linear organisation or be adapted in a non-linear organisation (an information point can be used in several learning unit).

For the narrative route, the third layer, Varano enhances how it may be hard to adjust classical narrative scheme (initial situation, complication, action or episodes, resolution and final situation) to a non-linear approach. Inspired by videogames, Varano deconstructs the narrative into several quests which have a beginning, an objective and an end and are composed of several puzzles or enigma (Figure 7 – Narrative and non-linear approach: introduction of enigmas (Varano, 2010).). Each enigma corresponds to a knowledge crossing and is meant to be solved thanks to the clues connected to this crossing (i.e. the information points):
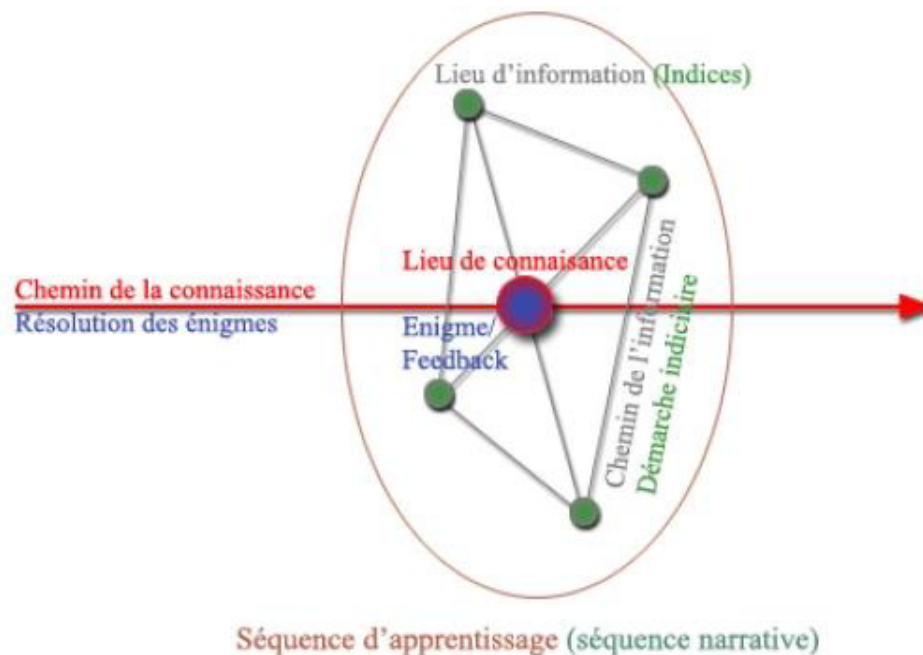

Figure 7 – Narrative and non-linear approach: introduction of enigmas (Varano, 2010).

2.7 Conclusion

The few examples of multimedia applications and interactive exhibitions we presented up to now will guide the concept of our project. If the reproduction of a particular stage set seems to lead the visitors to participate to the illusion of the "story" a museum wants to tell thanks to interactivity and immersion, we think that a

well preserved historical location like the Physics Cabinet should also conduce its visitors to engage with the story of Physics in the 18th and 19th century.

In addition to this, we believe that gameplays and learning games are the right solution to inspire our project and transmit knowledge in a playful way. The REXplorer and EUREKA! project showed us that games and videogames have the ability to captivate their audience. We are convinced that the MobExplore's offer can be pushed further by better connecting each step of the interactive journey to the others in order to be able to give more easily a global picture of the exhibit and its key messages. For this, we think that the trajectories of interaction and the third layer presented by Varano, the narrative route and its respective techniques, are fundamental. The organisation concepts and the routes developed by Varano seem to be appropriate to our project and we are going to develop similar schemes to establish our routes in the Physics Cabinet.

3.   Methodology and Objectives

All our work is related to the attempt to answer the following question: how do we lead the visitor of the Science Museum of the University of Coimbra to the autonomous exploration of the Physics Cabinet? If the review of the State of the Art already gave us some tracks, we are now going to explore the context and the reasons that led us to the development of this particular playful experience.

3.1 Objectives

On the website of the Science Museum of the University of Coimbra, we can read that the "*Physics collection of scientific and didactic instruments of the University of Coimbra is one of the rarest and most remarkable in Europe. It was initiated at the Lords College in Lisbon it was moved to Coimbra to found the Physics Cabinet, which was attached to the Experimental Physics Chair created by the Pombaline Statutes of 1772. For more than two centuries the Physics Cabinet was improved by new machines, instruments and apparatuses resulting from the development of experimental physics that took place mainly during the 19th century. Today, the valuable materials and the perfection of the work of the equipment that remains from the 18th century Physics Cabinet makes it a true work of art. Still occupying their original rooms and furniture these items reveal the true spirit of the*

Enlightenment in Portugal. The collection has more than three thousand objects including around five hundred ancient books".

This short text encloses food for thought. We are dealing with a permanent exhibition, quite "silent" as the objects are really briefly introduced, but in a unique historical space. What can we do to properly present the valuable material gathered at the Physics Cabinet? We would like to go beyond the use of replicas but not to substitute the tour guide. We aim to offer a different experience, with an original, interactive and immersive approach.

Our procedure is a bit different from the ones presented by Belaën in her studies as we are starting with an exhibit which already exists and was focused on a more classical objective: to present authentic objects. But it is also a thematic exhibit on Physics which may invite to interactivity in an authentic historical space and makes it easier to make the visitor enter the trip. We consider our approach as a way to complete, update and disseminate the offer of the Science Museum.

Taking those elements into consideration, the objectives of our project are to:

- allow experimentation to captivate and engage the audience;
- proportionate an autonomous discovery of the Physics Cabinet and contribute to the flexibility of the Museum offer;
- contribute to the multiplication and reach more people by constituting an alternative to a guided tour;
- link the Physics Cabinet's sites and objects, through spatial gameplay narratives and create what Ballagas and Walz call "an interconnected picture of the story of sciences" (Ballagas and Walz, 2007).

3.2 Approach of the problem

To be able to propose an integrated solution to the Science Museum of the University of Coimbra, we adopted a multi-angular approach.

First, we sought to know better the Museum itself and how it articulates with the University of Coimbra. My previous work experience with the Museum and the projects developed with the Museum in the first year of the EUROMACHS master made this first step relatively easy. We also aimed to understand the interest that the Museum staff could have in such a project and to work on its integration in its global offer. That's why a meeting with the director of the Museum was scheduled right in

the beginning of the project. The director, Prof. Doutor Paulo Gama Mota, enhanced that the museum did not have any existing exploration model for its 5 autonomous units and that it may be important to break the sequential visit to allow a free and custom one.

His inputs were also important to guide our research and our network, which leads us to the second aspect we focused on. It was crucial for us to deepen our knowledge of the collection, of the items presented and the stories that they hide to be able to present them correctly. This research took a big part of the beginning of the project.

We had another aspect to consider: several projects already have been developed around the Physics Cabinet (educational and institutional projects as well as external projects). An exhibition was organised in 1991, in Belgium, and showed over 140 instruments of the Cabinet's collection ("Les mécanismes du génie", Palais des Beaux-Arts, Charleroi). Several books are also available (we would refer namely the catalogue "Ingenuity and Art", 1997) as well as a comic strip ("Le secret de Coimbra"). Some 3D simulations were also developed for some instruments as part of a virtual visit suggested on the Physics Cabinet website and some podcasts are also in preparation. So we had to think what added value our project would bring and how we could take benefit of those elements.

At the same time, we reflected on the gains that the technology could bring to the project. We didn't want to overshadow the collection by using fulsome IT artifices. We had to keep in mind that the technology was only there to support and to enhance a cultural heritage. We also wanted to work on a solution that could easily be used by most people.

3.3 Process and activities

In our work, we followed some of the standard stages of a multimedia production for a museum exhibition mentioned by Economou, with echoes of similar steps in the articles written by Ballagas and Pereira and Roque: (a) Research on the content of the application; (b) Collection and organisation of the material; (c) Game design and prototyping; (d) Formative evaluation; (e) Integration in a museum exhibition; and (f) Summative evaluation of the program's effectiveness (Economou, 1998).

For this playful experience, we began with a research on the content, mainly through bibliography, but also thanks to some interviews with experts (with the former head of the Physics Cabinet namely, Prof. Doutor Décio Martins). This research made us consult several essential works to understand the history of science in Portugal and in Europe at this time. Thanks to this reading, we understood for example that the Physics Cabinet is an important display of the reform established by Pombal and that it was part of a larger European network. We tried to transform the elements we were learning about into contents which could be used in our project. For example, our reading conclusions led us to a set of key messages that we will develop below for the concept of our project. We also created items and characters cards to help us distinguish the characters that could have a role to play in our "reconstitution"(Figure 8 – Items and Characters cards with their key characteristics.).

Figure 8 – Items and Characters cards with their key characteristics.

On the other hand, the exchange with Physics experts was decisive because it allowed us to make links between the historical items we were seeing (and part of the history of science they represent), our reading and some more contemporary issues.

Thanks to the interviews, we were able to associate certain objects to some key concepts that are correlated to the exhibition. That's how some "routes" to explore the cabinet began to take form in our mind and we drafted some first sketches (Figure 9 – Items separation according to possible "routes").

To complete this approach, we decided that it could be elucidative to attend a group visit and see what explanations were given and what was the most interesting aspects for the visitors. We did participate in a scholar group's visit where only a few items were introduced to the children and where we could note what drew their attention.

To help us in our design we also took time to map the collection (Figure 10 – Mapping the collection of the Physics Cabinet). As the exhibit had been changed several times, there was no document presenting the current organisation of the Physics Cabinet. It is currently organised according to the "*Index Instrumentorum*" - a catalogue established by the Italian professor Giovanni Antonio Dalla Balla, who was the first head of the Physics Cabinet in the 18th century - and to the scientific themes and the Physics history. We thought that it was important to "take possession" of the space and to know exactly where the objects were presented as we were planning to have an interactive device which would lead the visitors to evolve in the two rooms that form the Cabinet. Once this map was done, we began to represent on the paper those routes we were drafting and the possible ways that the visitors could follow.

At this stage, we may consider that the collection and the organisation of the material were done and that we could go further with the game design and the prototyping. A few questions remained yet: how could we transform the linear routes that we imagined after the research on the content into challenging non-linear ways to explore the exhibit? How could we add a fun aspect to our project? That is what we are going to explain now in the next section presenting our project concept.

Figure 9 – Items separation according to possible "routes"

Figure 10 – Mapping the collection of the Physics Cabinet

4. Game Concept proposal

Taking into account the several aspects with highlighted in the state of the art, we may now reflect further in this presentation about the tone and aspect we want to give to our experience. We are going to apply the knowledge we gathered for our project to the three layers scheme referred by Varano (topographic, cognitive and narrative routes).

4.1 Definition of the artefact

The idea of the artefacts exists since the beginning of the project and was not changed. We are talking about a tactile game for a local use, addressed to smartphones and tablets, with a system of 3D QR codes. Our reference world existed and the visitors will evolve in the original place, but we don't want to reproduce it exactly. We want to get inspired by the persons and elements that inhabited the Cabinet, but we should not get stuck to them.

We are referring to a game here but our experience doesn't gather all the characteristics of a game (cf. Klabbers, 2009). A playful experience is a more appropriate term. Our visitors will be playing; they are not competing with each other ("*Agon*"). They are "doing an enjoyable thing" (we hope so, at least) and "performing an activity guided by the rules of a game". We are not expecting any particular skill or knowledge before the visit. The participant will be conducted through the knowledge existing in the Physics Cabinet thanks to a role playing ("Mimicry"). In that sense, we may assimilate the quests we are going to design to exercises ("An activity planned to achieve a particular purpose").

Our main aim is to interconnect items of the Physics Cabinet and expand the physical space thanks to Virtual Reality. For this, let's put the scientific objects to "speak" with the visitors. We intend to use a "game" as the organisational element of the experience. The narrative we aim to develop will give tracks to the visitors in order to make them discover the significant elements of the exhibit, the concrete and existing ones, but also the human aspect and the history of science. We indeed believe that an "items seek" approach will stimulate the curiosity of the visitors.

We would like to have a strategy that corresponds to Varano's directions: create a structure for the experience that locks the player into a preconceived space and be able to make him follow certain paths without noticing it. We are intending to produce a mixture of the *paida* (free-form of a game) and *ludus* elements (rule-driven game) (Klabbers, 2009). In his work, Varano mentions for example some action/reaction points that are automatically triggered by the position or the action of the player (Varano, 2010). That's something we also would like to explore. The sound of a person preparing or repairing an instrument can attract the visitor, for example.

Belaën concludes from her study that a previous knowledge of the story we are going to tell is important to make the appropriation by the audience easier. The codes' translation is important for the inclusion of the visitor.

"La logique de représentation basée sur l'analogie offre l'avantage d'être facilement lisible pour le visiteur, d'être suffisamment explicite" (Belaën, 2005).

We must find the common denominator that will be clear for the major part of the visitors.

4.2 Key messages and goals

"The design of cultural multimedia is inherently an act of interpretation and communication" (Economou, 1998).

So what do we want to communicate with this playful experience? As a conclusion of the research made on the Physics Cabinet, our main messages would be:

- the objects in exhibition at the Physics Cabinet are unique for their scientific value and for the message they transmit;
- the Physics Cabinet is a piece of the history of science in Portugal;
- the Physics Cabinet is important and relevant in an international network;
- the Physics in the 18th and 19th century are the preludes of today's science.

After reading Belaën's conclusions on the climate change exhibits, we may wonder if we prefer to produce a system to reflect the scientific method (i.e. show to prove) or to lead the visitor to act on/change his life.

"L'objectif est de faire réagir le visiteur en simulant les retombées des phénomènes dans sa vie quotidienne" (Belaën, 2004).

For this permanent exhibit, we don't disseminate a message that may make the visitors change their daily life. However, it seems important to us to let him know (or remind him) that the objects he has in front of him led to objects and systems in use today, as the "Model of the *Bréguet* electrical telegraph" for example, which constitute a basis of our SMS system.

4.3 Process and outcomes

From our interview with Prof. Doutor Paulo Gama Mota, we retained that the Physics Cabinet of the University of Coimbra was at its creation part of a network of European university cabinets (Padova, Uppsala …) and had a major role in it.

The different books we consulted gave us a global overview of the history of the Physics Cabinet. When the Jesuit Order was extinguished by the Marquis of Pombal in 1759, the scientific instruments belonging to the royal family (for the education of the princes) seem to have been first transferred to the "College of the Nobles" (1761-1772) in Lisbon and then in 1772 to the University of Coimbra which will become the banner of the education reform led by Pombal at the time.

The instruments were intended to be actually used and not only to be seen as it was usual with the natural sciences. Fruits of the Enlighten period, the Physics instruments are the hyphen between the theory and the experimentation. The Physics Cabinet was a mirror of scientific innovation at a given moment. It has a role to play in teaching and for the research in Physics, but also in the dissemination of science thanks to experiments and public lectures, for example the public experiments on Saturday at the "Theatro das Experiencias".

Our bibliographical research made us discover a set of elements which may be used in our project. Several persons had a relevant role in the existence of the Physics Cabinet, from the heads of the Cabinet like Dalla Bella or more recently Henrique Teixeira Bastos and Mário Silva to the several pedagogues (Padre Teodoro de Almeida). But also the instruments constructors (Joaquim José dos Reis, Schiapa Petra, Francis Watkins or João Jacinto Magalhães), the "helpers" or "demonstrador" (António Rodrigues, Caetano Rosado, Teotónio Brandão), the "guards" or "bedel" (Alexandre José Monteiro and Francisco José de Miranda) and the more recent "preparators" or "preparadores" (António Ferreira, Francisco Galvão). Several books used during the Physics lessons in the 18th and the 19th centuries which still lay on the shelves of the Cabinet's shelves may be used in our project.

As a conclusion of the articles we read about the Physics Cabinet, we defined 6 axis of work for our project to be designed:

- the teaching reform led by Pombal;
- the physics concepts;
- the aesthetics in science;
- the European connections of the Cabinet;
- the Physics for society;
- the basis of today's science;

It was quite easy to select certain objects of the exhibit and to connect them according to this thematic approach (Figure 11 – Items separation according to possible "routes"). We defined the point of interest of the Physics Cabinet thanks to our reading and the ideas given by Dr. Décio Martins. At that time, we were already fully conscious that objects, but also the space at itself and the furniture were important. From this point, we started to prepare some autonomous narrative "islets" around the 6 axis (Figure 12 – First sketch of linear routes).
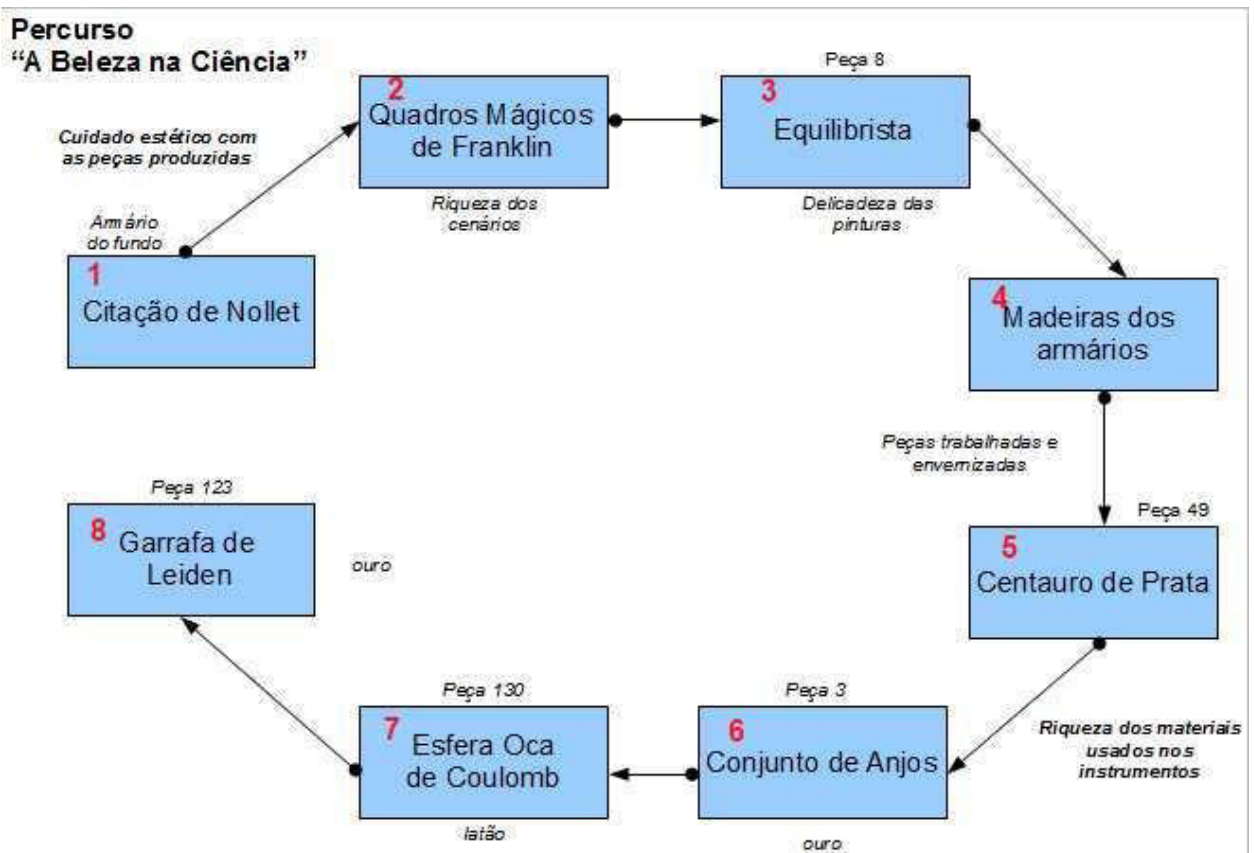
Figure 11 – Items separation according to possible "routes"

However we mainly defined linear ways to discover the Physics Cabinet and a second step was to imagine connections between those routes and ways to jump from one to another to "spice" the playful experience.
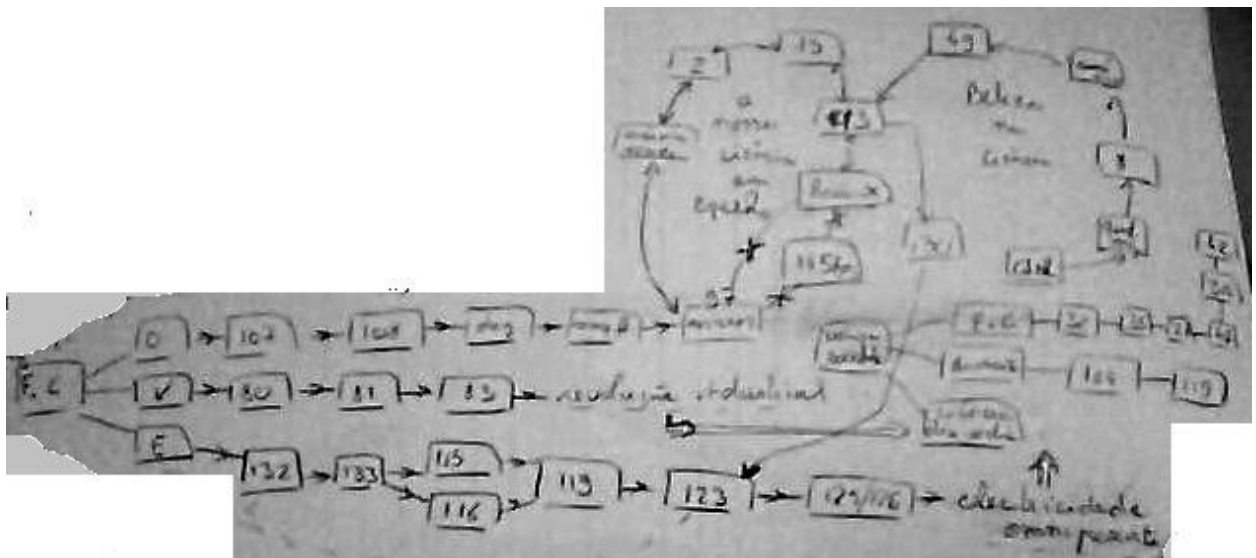
Figure 12 – First sketch of linear routes

After settling those grounds, some aspects still needed to be well thought like the role of the visitor/player we intend for the playful experience or the approach we prefer (only for national visitors? Also for foreigners? For non-expert only?, for a single user?, or with a possibility to be explored in groups? etc.). We will get into such a detailed level in the next section about Game Design.

4.4 Constrains and Challenges

The specificity of the Science Museum of the University of Coimbra exposed us to several limitations, or at least to elements to consider carefully before designing our project. We will separate those elements into three categories: locally-driven constrains, context-driven constrains and challenges related to the mechanism of the playful experience.

In this first part, we are going to describe the questions we were facing when we began to reflect on our design for the Physics Cabinet:

- Our main difficulty is connected to the time consistency and the historical integrity of the playful experience. The exhibit in the Cabinet gathers objects from the 18th and 19th century so we wondered how we could find transversal elements for both rooms. The difficulty is finding a story that

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appropriately bridges the different historical periods. In REXplorer, Ballagas and Walz use the "haunted house" and "techno-magic" themes to bridge the historical movements in a non-linear story (Ballagas and Walz, 2007). In our case, we began to think about our character cards as a way to establish connections between those two periods and also with the present time.

- From our reading on other experiments and from the moment we began to have the first ideas for our narratives, we began to think about the way to deal with the constraints of museum and galleries for noise, pictures and other distractions/ interruptions. Would the Science Museum allow the visitors to take pictures of the original and precious objects of the exhibit? Will the cabinet glasses be appropriate for our technology, for example? Busy museums may not be the ideal stage for such an experiment. We believe that the Physics Cabinet can still welcome the project, as it has a moderate audience but it may become problematic with large audiences. As our experience is based on interactivity and immersion, we considered the possibility to make the visitor use headphones during the visit as a way to isolate him/her from the other visitors and not disturb them, above all if those are not engaged in the playful experience. But this isolation may also have prejudicial effects if we think that the visit could be enriched by the exchange the visitor could have with other members of his/her family or group.

- We were also concerned by the fact that no possibility is offered to the visitor to manipulate the objects. Yet we have seen in the state of the art that tactile sensations, corporeal participation are a way to immerse the visitor. We wonder then if this lack could be counterbalanced by the 3D simulations that exist for some of the scientific objects to allow interactivity. Would the scenario itself contribute to the immersion?

On the other side, some of our challenges were related to the fact that we are conceiving an interactive and playful experience for a museum. An important aspect for such a process in museums is to convince local guides that we are not attempting to compete with them and even recruit them for help and content oversight (Ballagas and Walz, 2007). For Roussou, the role of the museum educator, guide or facilitator is critical in structuring the interactive experience so that children can build bridges between different perspectives and gain a deeper understanding of the content

(Roussou, 2004). We agree with this argument. However, we doubt that the Science Museum of the University of Coimbra will be able to provide this facilitator for each visit to the Cabinet.

We saw in the state of the art above that according to some researchers, fun interactions and serious contents may clash. To be able to properly use devices like smartphones or tablets, the information must always be short but still informative to catch the visitor's attention. How do we preserve the authenticity and the credibility of the museum and its contents with such a restriction (Roussou, 2004)? We also remember the quote of Florence Belaën when she states that in permanent exhibits, museums' curators aim to achieve a complete and rigorous explanation of a phenomenon (Belaën, 2004). Permanent exhibits have to be self-standing in terms of contents, as they cover neutral and timeless thematic. How can we also achieve this goal with a playful experience? What are the effects of interactivity on conceptual learning? Does it work the same for adults and children? (Roussou, 2004)

Those last questions led us to reflect on the limitations of the mechanisms of the playful experience itself. Does the immersive interactive exhibit not reflect enough scientific contents? Are we producing scientific entertainment? Edutainment? How could we find a proper balance between Didactics vs. Emotion and Form vs. Substance? The vulgarisation of the sciences we are aiming to achieve will be merely a sensitization and a scientific show? Are those immersive techniques able to explain scientific researches? (Belaën, 2005) We would like to avoid such extremes and designing what could be called a scientific show. On this aspect, we count on an evaluation of the experience made be the stakeholders and the audience to inform us about how successful we were in fulfilling that aim.

We are also concerned about the way the playful experience will be received by distinct audiences (children, adults, inhabitants, foreigners, etc.). How to design accessible trajectories/routes that support varying abilities and skills? How to dose adequately mastery, difficulty and fun (Gee, 2007)? How do we do to pass from a linear story to a challenging non-linear story? And what about people who would prefer a linear story after all? We are aware that we cannot please everybody with our design, but our playful experience should be addressed to a general public to serve properly the interests of the Science Museum of the University of Coimbra.

Last but not least, we also have to be careful with the project we are designing in order not to produce a mere navigation in a virtual space and to really promote

interactivity, i.e. active participation by the user in what happens in it. We remind that for Roussou "active participation means placing the user in a central active role with the ability to modify the environment (Roussou, 2004).

Furthermore dramatic narratives and interactive environments may quickly become antagonistic. We have to be careful in order not to maintain one at the cost of the other. We will do our best not to forget the cognitive route (Varano, 2010) and the big picture: when designing the details of the experience, we are tempted to forget about the key messages of the experience and choose the easy way.

5. Game Design

In this part of our reflection, we are going to assume the role of a game designer and define the mechanisms of our playful experience, i.e. (1) what choices our visitor will have in the universe we are going to create, (2) what impact those choices will have and (3) what information he/she will receive from the game.

By revealing those three aspects, we will try to answer a set of questions:

- May the playful experience integrate affordances as a way to learn and, if so, which ones?
- What is the goal, the "win state" of the playful experience? Is the scientist goal the production of knowledge to solve deep problems? Should we try to reproduce this specific process? The way of thinking the playful experience is deeply connected to the goals of the experience.

5.1 Process and outcomes

We informally imagine the global framework of our experience. One of the first "ingredients" we defined was that we were working on an individual approach of our playful experience. This choice was made taking into account that it would be easier to implement the experience, at least at a first stage, and also because of the local itself: the Physics Cabinet is not that big so that we can have different groups going from one spot to another, all looking at a single object[2]. We also decided early that

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2   We don't totally exclude the possibility of forming groups to explore the project but they must be small at this point to allow a reflection on what is shown at the Museum. Besides, from this first version of the playful experience could appear a second one that for example distributes different roles to a larger group to create new types of interactions.

we would have a mix use of the existing 3D simulations, interviews, clues, sounds, the comics on the Physics Cabinet, etc. to tell the story (multimodal narrative).

Based on the literature, we defined an approximate number of stages/stops during the visit. We can refer for example to the 15 to 25 advisable stops in Mobexplore for a 1-2h visit. This question is directly connected to the question of the duration of the game. There is a relation with the typical expected duration of an exploratory activity on the Museum during visits, but we could not find empirical data on this nor analysis made by the Museum itself. The six routes we are imaging may represent a long visit to the Cabinet. The on-site evaluation should help us to estimate if it is too much or not. We also rely on the possibility given by the game of not approaching all the quests but we have to remember that we want to provide a full picture of the exhibit and not only fragments and that leaving without achieving all the "win states" may be frustrating for the visitors.

As we said before, our concept mainly relies on the creation of autonomous narrative "islets" around six axes. Initially our design process focused on the route "The aesthetics in Science". We used this first example as a template. Thanks to the objects we selected, we prepared a Petri Net which connected the objects among each other in a sequence and unfolded the action (Figure 13 – Final version of the Petri Net for the Aesthetics route).

To realise the diagramme, we tried to respect the idea of a trajectory through interpretation and its several phases: approach, engage, experience, disengage and reflect (Figure 3 – The five stages of Fosh's local trajectories (Fosh et al., 2013).), by breaking down our actions. We also reminded the advice given by Benford et al. to only give the "official presentation" after the visitor has engaged with the object.

The main difficulty we had at that point was to produce an open sequence that would allow the visitor to explore the route in an order he would define by him or herself and not make him follow a predefined order. In fact, we thought that the experience would be much more interesting this way. Here we were mainly guided by the technical solutions and possibilities, which fortunately allow us to give some freedom to the visitor.
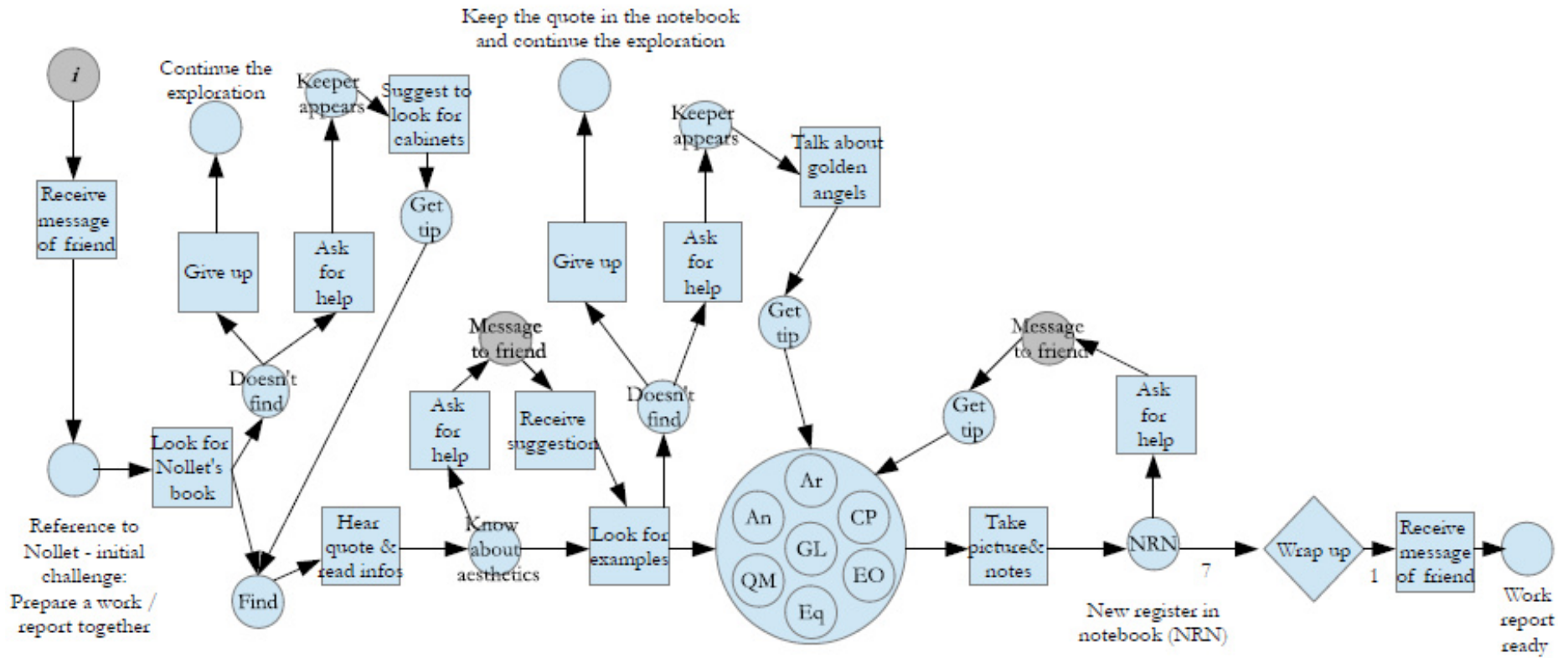
Figure 13 – Final version of the Petri Net for the Aesthetics route

In parallel to the Petri net, we worked on the story telling. A first sketch of a narrative was written. With the evolution of the process, this first possible narrative changed a lot in order to become an interactive narrative and to allow the identification of the visitor. That's when we really introduced a character in the experience: we imagined that we could propose the visitor to play the role of a student of the University of Coimbra who is facing several quests. It is for us a way to connect directly our playful experience to the context of the Science Museum. We also thought that the role of a student would not lock us in a too strict framework.

From the first Petri Net, where we clearly defined some actions and reactions, we went to a more detailed structure which will help us to technically implement the route. For each activity, we defined a title, a message, an instruction and an image to be used. At this point, we were entering the prototyping phase (see below).

Meanwhile, some other questions were raised which had a direct impact on our design. We wanted to give to the visitor the possibility to abandon a quest and to get back at it later to avoid having him/her getting bored if the quest is not corresponding to his/her expectations. When we considered this possibility, other questions were raised: how do we enable the visitors to keep trace of what they have seen even if they did not follow any pre-thought route? How do we indicate their progression? How do we give feedback to the visitor during his/her playful experience? How can the visitor get a global idea of the messages we wanted to give at the end of the visit? That's when we thought that the idea of a laboratory notebook, as a way to keep a trace of what has been done, of the "tokens" somehow, could be the solution. Each step is then registered and means that a bit of knowledge has been transmitted. Later in the process, we thought that the figure of an imaginary teacher could complete the role of the notebook and intervene from time to time to give feedback to the visitor (e.g. periodic actions).

We are now going to refer to the limitations we are facing with this project and their impacts on our actual design features[3]. One of the main concerns for such a fun experience is the customization (e.g. difficulty levels, playing different characters, etc.). For example, we wondered if a teacher role was a good idea for someone that

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3 Gee refers several basic design feature like interactivity, customization, strong identities, well ordered problems, pleasant frustration, cycle of expertise, deep & fairness (Gee, 2007).

already is an expert. But it seemed too complex to implement at this stage of the project. We aim that the chosen character of a student will allow us to create a range of different situations that imply different mastery and goals. It should also allow the possibility of having the main character (=visitor) to live an experience through different points of view. This aspect could namely be interesting to present the different positions about teaching in the late 18th century.

This last point leads us to the last aspect of the reflection on our design: how do we "spice" the visitor's experience? As we saw before, we intend to create a non-linear narrative. One of our first solutions is to resort to certain physical spaces or to the resolution of an enigma/puzzle which free the access to the other story line. The navigation between times and characters is going to be the only way to solve all the puzzles. We also found some scientific objects that could establish links between the thematic routes and thus allow the visitor to "jump" from one to another like shortcuts. We also wanted to allow a range of possible answers and solutions that would challenge the visitor and enhance the scientific attitude.

Finally, what space for chance and hazard should we let in our playful experience? Should we insert a "fatal aporia" (difficulty, cf. Ryan), for example? Or, as least something that would challenge the visitor but not discourage him/her? We are not designing a videogame, but a device-based experience. We don't feel that an overturn is mandatory, as the visit has certain duration but we aim to introduce a few elements among the quests that will surprise the visitor, namely thanks to periodic actions and isolated challenge (e.g. a character interrupts the visitor to ask for help).

5.2 Synthesis: game scene

How does the experience look like?

To resume in a few words, the playful experience we designed turns the visitor into a young student of the University who will discover for the first time the Physics Cabinet and will be challenged by several virtual characters. They will receive the visitors, challenge them and/or help them find key elements to understand the importance and the role that the Physics Cabinet had for Physics teaching in the 18th and 19th century.

All the interactions occur thanks to Oriverse's smartphone application under the form of short messages received on the phone (Figure 14 – Oriverse smartphone

application for the playful experience). The visitors are invited to move independently inside the rooms and to look closer to the objects they have in front of them.

Figure 14 – Oriverse smartphone application for the playful experience

At this point, the playful experience has a simple graphical image that may be improved if this first "seed" is gaining life. It uses the general template of Oriverse's framework and includes photos, sketches and texts about the items of the Physics Cabinet. Those information elements may be enlarged when the platform technology allows and we can think about short expert's interviews or videos of live scientific experiences related to the item to be added. We defined a colour code to be associated to the several quests (6 colours) and the "wheel logo" of the Museum may be used to identify each of them along the path.

As we are talking about a project for an individual exploration, we may not introduce elements which could disturb other visitors. The music and sounds of the experience is an aspect we did not explore further at this stage, but it could help to materialize the different episodes if the use of headphones is generalized. Before the prototyping phase, we imagined that sounds could be a way to attract the visitors to a certain place of the exhibit.

Summing up: an original network for the playful experience

While we were advancing in the preparation of the State of the Art for this project, we thought that it may be relevant to use Klabbers' matrix to present the outcome of the work (Klabbers, 2009). The table below shows the architecture of the game and its main elements (Figure 15 – The playful experience according to Klabbers' matrix).

Architecture of the game			
Social System	Syntax (Form)	Semantics (Content)	Pragmatics (Usage)
Actors	Number of player *1* Number of game places of actors *1: the Physics Cabinet (pervasive game and augmented reality)*	Roles *A young student at the University of Coimbra (studying Physics or not)* Composition of roles in social organization *student, detective, helper, etc.*	Learning context: types of steering *text messages, photos and sketches* Learning goals: kinds of knowing *theoretical and empirical knowledge on Physics* *personal skills (reflection, deduction, etc...)*
Rules	Game manipulation set: preparatory rules; start & stop rules *start and stop rules defined with a welcome message when the visitor enters or get out of the rooms* *Possibility given to the player to stop the game at any time* Rigid-rules Principle-based rules Free-form	Relationships between roles, communication rules, procedures *exchange based on virtual messages* *varying roles and relationships* Evaluation of places for resource allocation, and relative position within team of players *position within a team of players not needed (individual exploration).* *Yet the experience could*	Team of game facilitators: *we may imagine that the Museums guides may interact with the visitors, for example during the exploration of the playful experience by a school group, but not for a regular visit* Format & instructions for rigid-rule vs. Free-form: *basic instructions should be given when the visitor enter the playful experience check-in*

	Principle-based rules: a framework has been designed, but the visitor is free to explore it in the order he prefers *No scoring system* Initial game positions Allowable moves Final games positions *Initial position: "caloiro" (freshman)* *Final position: graduated student* *This evolution may be signalled thanks to elements of the real academic tradition in Coimbra*	*be enriched by exchanging with family e.g.*	*The experience is based on 6 quests identified by a colour + advice to not only read each QR code individually* *+ some of the quests will only appear when other are solved* *+ free to leave a quest for another at any point and come back* *+ notebook as a way to gather tokens and get an idea of what has been achieved* Assessment functions: *role of an imaginary teacher that the visitor can consult occasionally*
Resources	Game space Set of game positions set of pieces *Physics Cabinet: two rooms* *+/-75 positions (including helpers, notable zones for the evolution of the game)* *+/- 40 objects presented (not mandatory, "self-service")*	Positioning of pieces: meaning of cultural, socio-economic situation *accurate picture of science and science teaching during and after the Enlightenment* Set of occupied & available positions *introduction of fake QR codes (information available in the catalogue of the exhibit afterwards)*	Materials: Equipment Paraphernalia Facilities *tablet / smartphone* *headphones* *virtual notebook* *camera* *connection to Internet*

Figure 15 – The playful experience according to Klabbers' matrix (Klabbers, 2009).

For this synthesis, we also would like to use the state of the art as a background to present our project and game scene construction, namely by referring Ryan's networks, the topographic route, cognitive route and scenario of Varano and the trajectories of Benford and Fosh.

We believe that the first preview we gave of the playful experience thanks to the Aesthetics route is inspired by Ryan's directed network presented on Figure 2 – Networks and interactive narrativity (Ryan, 2001). The quests we imagine evolve as a flow chart, joining a non-linear approach and some flexibility (Figure 16 – Example of directed network (Ryan, 2001).).
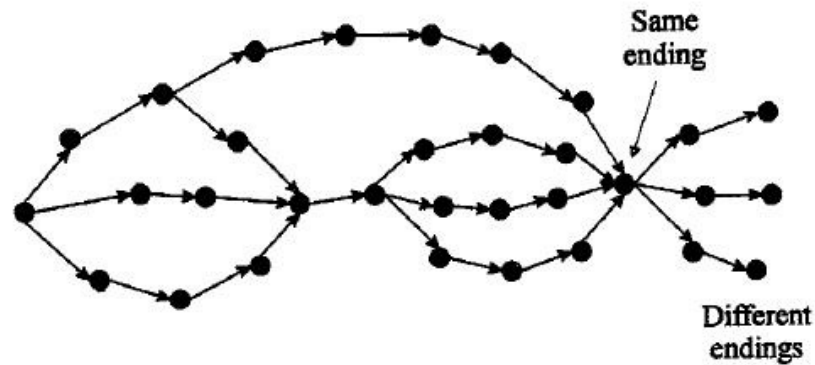
FIGURE 9 I The directed network, or flow chart

Figure 16 – Example of directed network (Ryan, 2001).

The visitor is facing several possibilities from the start (several quests) and each one will be developped on its own, with possible interconnections and crossings. But the freedom is not total and the visitor is led to follow some predetermined paths. That's because of that aspect that the playful experience differs from a network like the Masse structure of adventure games also presented on Figure 2 – Networks and interactive narrativity (Ryan, 2001).

As we saw before, we followed the ideas of a trajectory through interpretation and its several phases to design our experience and the Aesthetics route. We may detail our distribution as follows:

- approach (the visitor has to look for an object)
- engage (the visitor has to act to begin the experience, e.g. reading the QR code)
- experience (the object to be discovered implies an active participation from the visitor)
- disengage (the visitor clearly understands when he should take the following step, e.g. reached outcome + tip for next object)
- reflect (the visitor is kindly led to reflect on the object he just saw and on its connection to the whole exhibition while he is looking for the following one).

This effort may finally be represented in a diagramme similar to the one presented by Fosh (see Figure 3 – The five stages of Fosh's local trajectories (Fosh et al., 2013). and Figure 17 – Example of trajectory in the Aesthetics route).
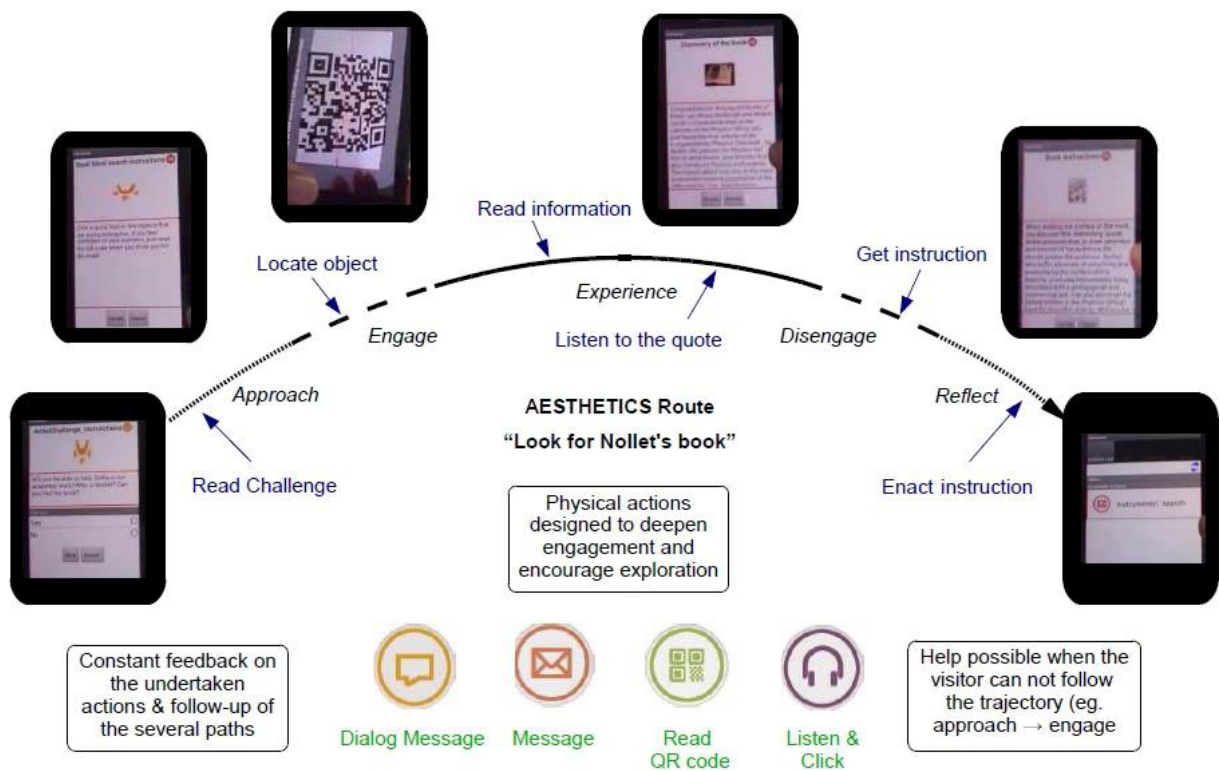
Figure 17 – Example of trajectory in the Aesthetics route

This 5-steps trajectory reminds us the information path refered by Varano (see Figure 7 – Narrative and non-linear approach: introduction of enigmas (Varano, 2010).). The user of the multimedia application is not just gaining information about an item at an information crossing. The need to move and to link two objects is part of the learning process itself. It is by associating two items because of the richness of their details or the quality of their material that the visitor will understand the beauty of the Physics teaching instruments.

By overlapping a narrative to the topographic and the cognitive routes, each information path become a process to gather clues - that we would call token in a videogame – in order to bring elements to solve the challenge – that would become a quest in a videogame. Thanks to all the information crossings, the visitor is able to respond to the application's initial challenge (Figure 18 – Adaptation of Varano's layers to the Aesthetics route (details)).
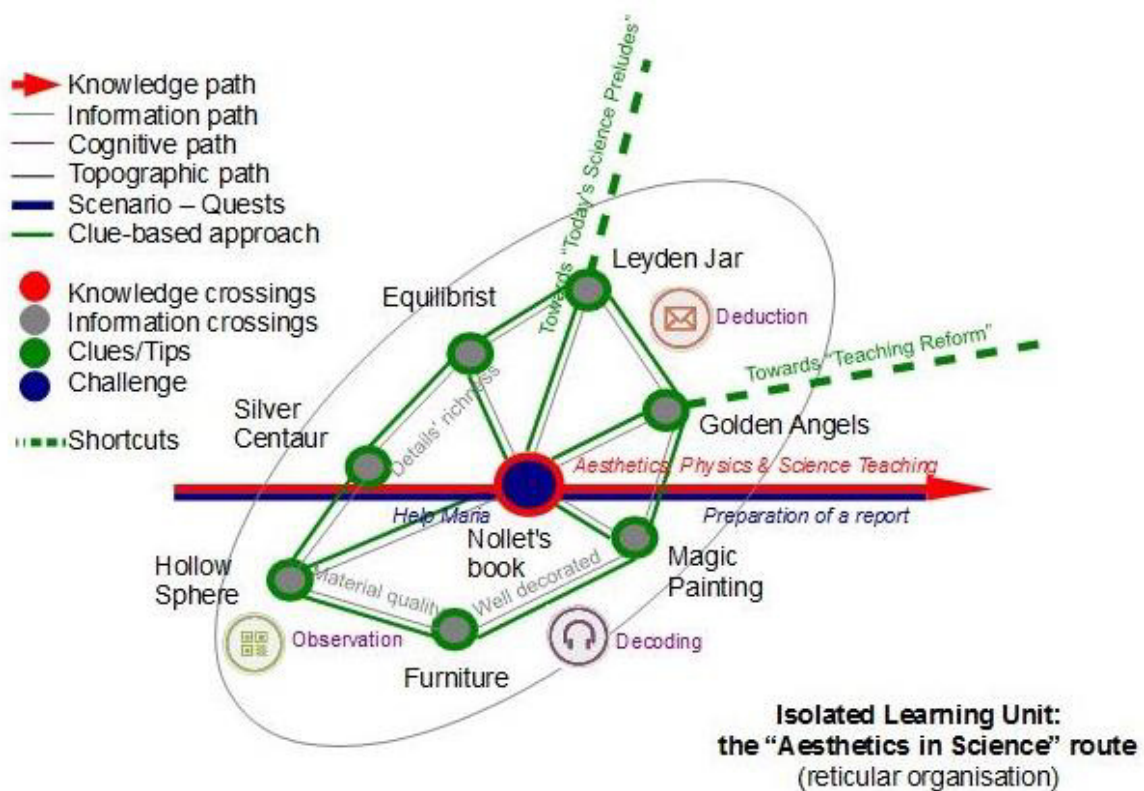
Figure 18 – Adaptation of Varano's layers to the Aesthetics route (details)

After looking at one of the "islet" of the playful experience, let´s frame it in the global exploration of the Physics Cabinet we designed. We imagine a visit where each learning unit/quest can be approached individually, depending on the curiosity and the availability of the visitor. Some of the items of the exhibit can be used as bridges that liaise different units and allow a hypertextual approach, as described by Varano and Ryan. That's what we represent as "shortcuts" in the diagramme of Figure 19 – Adaptation of Varano's layers to the playful experience.
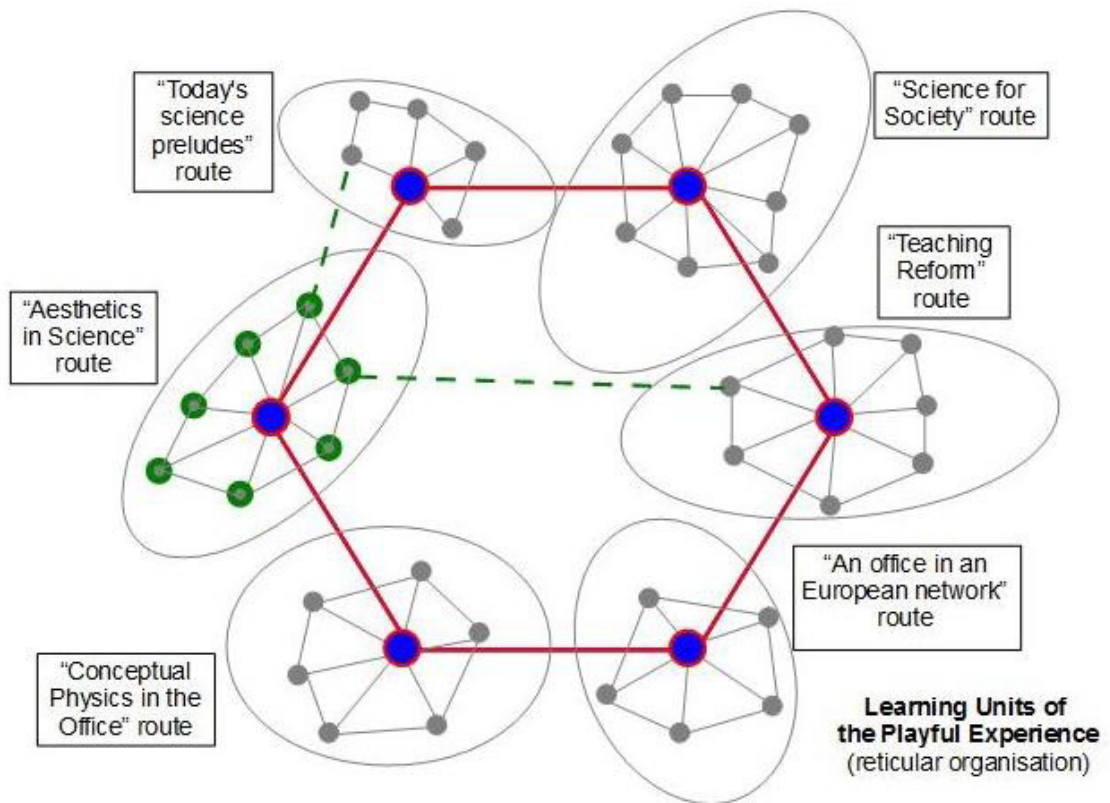
Figure 19 – Adaptation of Varano's layers to the playful experience

5.3 Prototyping and Playtesting

Prototyping the playful experience

The main objective of this phase of prototyping is to transform the flow model we developed into something concrete on a screen (a message, an image, etc.). For this, we used an augmented reality pervasive gaming framework created at the Department of Informatics Engineering (DEI) of the University of Coimbra: Oriverse. Oriverse is a platform for creating and managing pervasive games that are then played through Oriverse's smartphone application (Figure 20 – Oriverse's Backoffice: network of the playful experience). According to Benford, "pervasive games extend the gaming experience out into the real world". That is the case of Oriverse which gameplay progresses based on the player's location, the time of the day and other real elements.
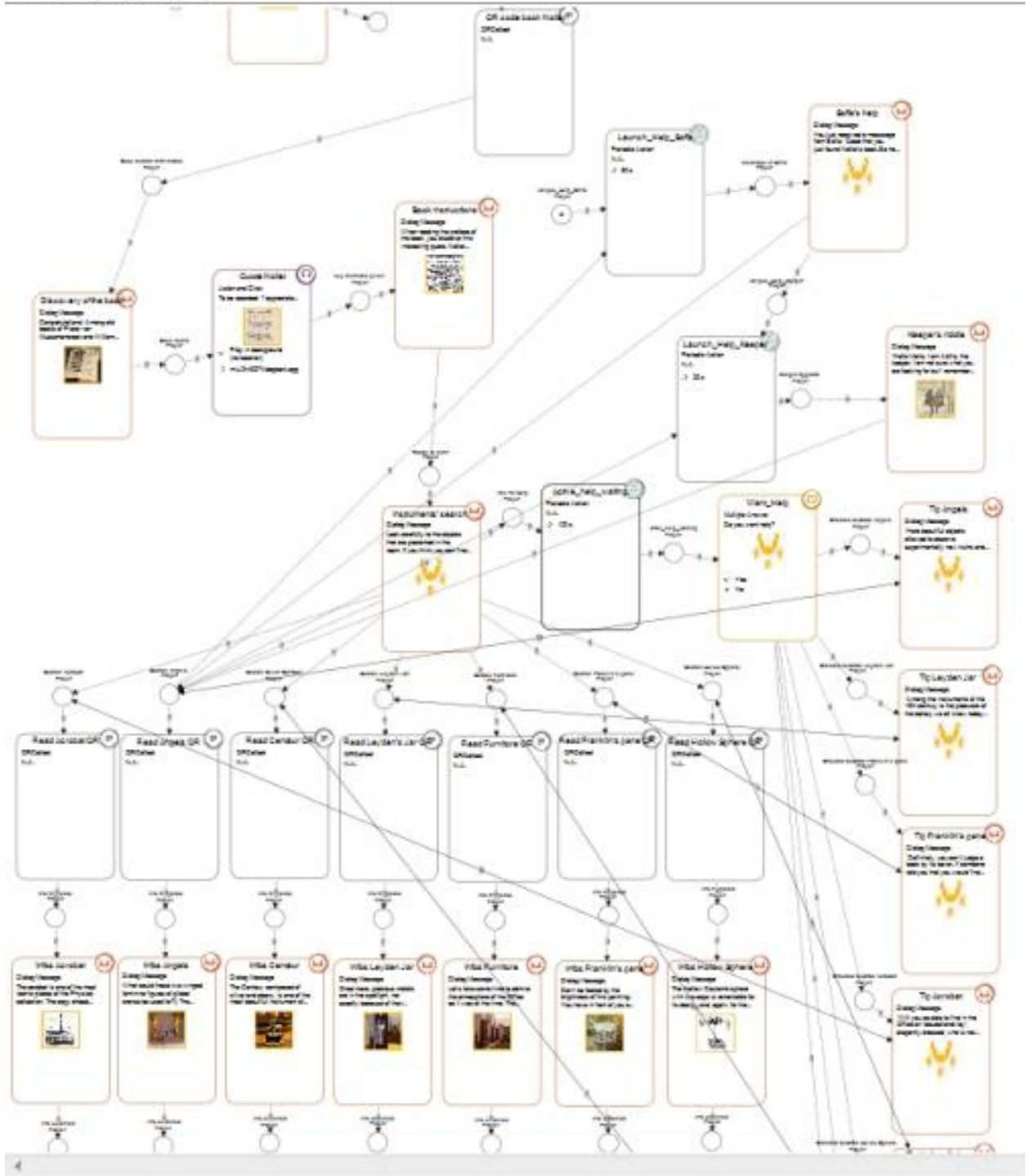
Figure 20 – Oriverse's Backoffice: network of the playful experience

At this stage, we inserted the Petri nets we designed for the Aesthetics routes into Oriverse's backoffice. To be able to proceed, we had to reach a sufficient level of details (title of the action, what is the visitor seeing and reading on his/her device

(text + image), what is the action chain, what are the instructions and clues to pursue the quest, etc.). We actually added to the platform the texts, images and questions that the visitor would receive on his/her smartphone (Figure 21 – Details for the insertion of the Aesthetics route in Oriverse).

The insertion in Oriverse's backoffice of our aesthetics route led us to some changes. As it is difficult to implement geo-localisation indoor, we had to rethink the beginning of the "quest" for example, as it can't start automatically at a certain point of the Cabinet. On another side, it is only when graphically linking the elements one to the other that we saw some incongruities appearing and the network getting more complex. We really can talk about adaptation(s) during prototyping and the exchange with Oriverse's manager was really valuable to get clearer ideas about the playful experience. Even at this early stage, we had to think about the whole experience we were designing, in order to respond questions such as if we should aggregate or not the several routes in only one "technical" experience. Then we decided to run a first test with the application in order to understand how the experience would unfold and if the path would be readable and feasible for the visitor.

Conclusions of Playtesting

For the playful experience, we ran two test phases. The first phase was realized outside of the Physics Cabinet, to check only the unfolding of the gameplay and the reaction of users who are used to deal with pervasive games. We obtained an interesting feedback that was then used to work on the design review.

For example, some sequences were not appropriate and we had to change the order of some parts of the network, like the congratulations message and the automatic help messages. Those aspects corresponded to some basic structural changes in Oriverse's backoffice but may transform the experience.

The first test also pointed out some deeper problems. The users lacked contextualization about the space of the Physics Cabinet and the objective of the playful experience. As the Aesthetics route is only part of a bigger project, we did not give much attention to this aspect but it is crucial from the stage of prototyping and playtesting.

Route "Aesthetics in Science

N.	Title	Type of action	Message	Instruction	Image	Localisation	Note		
1	Introduction		NONE	This quest should begin in the 18th century room (to respect Nollet's historical time)	Background colour: yellow	Entrance of the 18th century room			
2	Initial challenge		"Hello Maria! I heard that you currently are at the Physics Office. Do you think you could give me a hand? I have to prepare a report about the teaching of experimental physics and the physics instruments. My teacher talked about a book of an abbé, Jean-Antoine Nollet. Do you know him? Sofia"	Will you be able to help Sofia in her academic work? Who is Nollet? Can you find his book?	Background colour: yellow	Entrance of the 18th century room (exact point??)	Or Dialog Message? At the end of the instruction, we should give the visitor the possibility to day YES (and to go to Point and Click) or NO.	Actions	
4	Blind search of the book		Give a quick look to the objects that are surrounding you. If you feel confident of your success, just initiate the "Search" function.	When you think you hit the mark, just click.	Background colour: yellow		What radius for the activation of the search? The help option should already be available		Dialog Message
5	Discovery of Nollet's book		Congratulations! Among old books of Pieter van Musschenbroek and Willem Jacob 's Gravesande kept in the cabinets of the Physics Office, you just found the first volume of the "Experimental Physics Classes", by Nollet. His passion for Physics led him to write books, give lessons but also construct Physics instruments. Nollet was one of the most proeminent science popularizer in the 18th century.	Click below to start flipping through Nollet's book.	Background colour: yellow	Cabinet Z	photos to be substituted by an original taken at the Office		Dialog Answer
6	A very well hidden book		It seems that you are lost somehow. Do you wish to continue to look for Nollet's book?	Please click below to continue (YES or NO)	Background colour: yellow		times event? After a few minutes?		Multiple Answer
7	Abandon at stage 1		You were not into learning about the teaching of experimental Physics now. Maybe next time.	Feel free to go on with the visit of the Office. You may meet some unexpected characters on your way.	Background colour: yellow				Check-in
8	Assisted search of the book		Several persons have worked for the Physics Office since the 18th century, from the directors of the Office to their helpers and keepers. One of them should be able to help you in your seek.	Click here to proceed.	Background colour: yellow				Enter Proximity
9	Meet Abílio		"Hello, I am Abílio, one of the keeper of the university. I've been working here as a "bedel" for several years. Do you think I can help you?"	Please click below to continue (YES, I am searching a book written by an abbé)	Background colour: yellow				Exit Proximity

Figure 21 – Details for the insertion of the Aesthetics route in Oriverse

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The testers were also confused by messages that ended with a rhetorical question. In our view, those questions intended to get the visitor interested and involved, but the users were expecting a practical action after those messages. As nothing occurred, they felt lost. More generally, it came up that the narrative was not strong enough to embrace the user/visitor from the beginning to the end of the Aesthetics route and to liaise the different elements of the experience.

Figure 22 – Running a test on the spot is essential

A second test was then conducted on the spot, i.e. in the Physics Cabinet of the Science Museum of the University of Coimbra (Figure 22 – Running a test on the spot is essential). This second phase was important to analyse the movements associated to the smartphone's guidance. The overall balance of the test is positive: the playful experience makes the visitor walk through the two rooms of the Cabinet and look closely to the items presented.

As we realized two sets of tests, the localized test also allowed us to compare the user's expectation and the use he/she made of Oriverse's clues during practice. If the tip about the localisation of Nollet's book seemed vague outside the Physics Cabinet, for example, it made sense once the user was on the spot. However, one of the users expected to see the book featured on the shelves, which does not happen (the book lays among other old books). That's the kind of feedback we were able to gather thanks to the test. We also were able to discuss about the optimal localization of the first QR code that initiates the Aesthetics quest and other details. During the visit we faced the problem of the internet connection inside the Physics Cabinet. To implement the playful experience, the Museum should consider an option to grant free internet to the visitors.
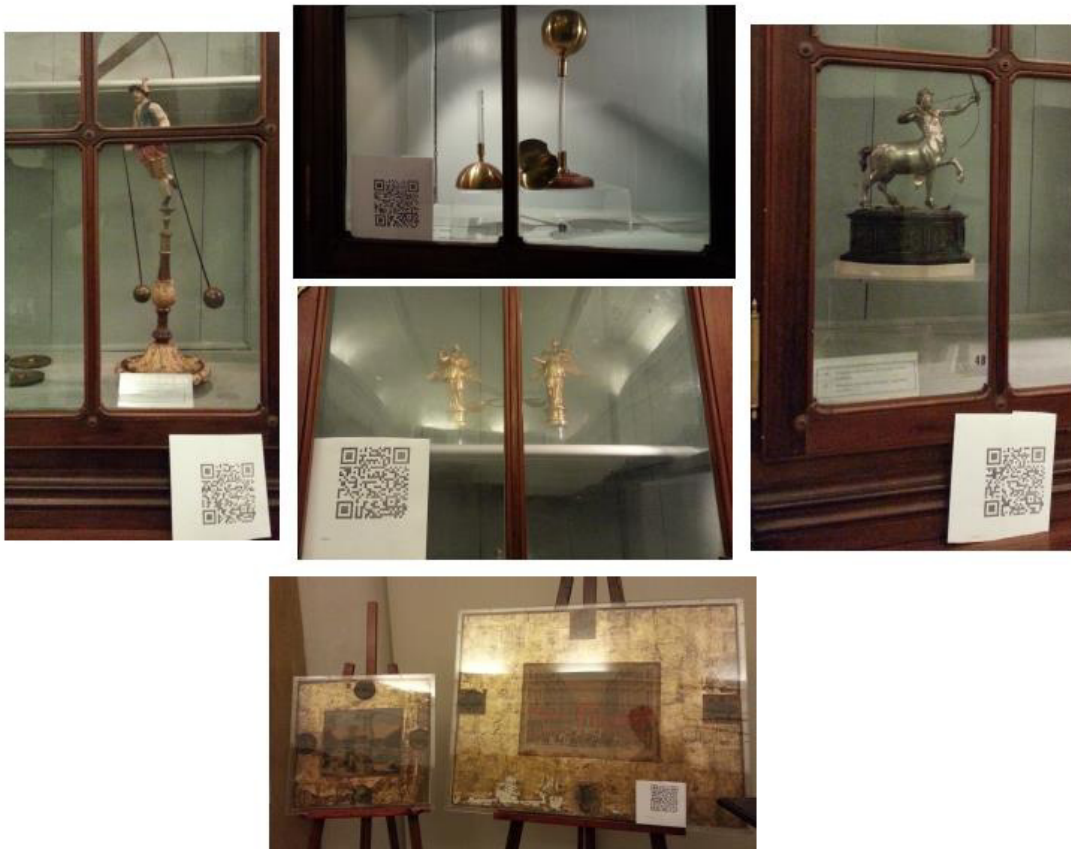
Figure 23 – Some QR codes of the Aesthetics route

At this stage of the project, we only put QR codes to less than 10 objects selected for the Aesthetics route (Figure 23 – Some QR codes of the Aesthetics route), which somehow warps the experience. Up to now, the number of selected items seems suitable to the visit duration and may be complemented with other routes. The test should be more effective with the complete installation, i.e. the six

quests. During the test visit, the idea of including false QR codes with no information associated was also launched as a way to spice the exploration.

Design review

Following the two tests we ran for the playful experience, we had to adapt the project and entered the design review phase. In this part of the process, we took into account the feedback we received from the different users. We tried to analyse the user-friendliness of the project. A substantial effort was made in order to improve the narrative associated to the Aesthetics route. Some of the gameplay contents had to be rewritten and more elements and characters were added in order to obtain a more dynamic action and thus captivate the visitor.

The insertion of a first paragraph presenting the two rooms of the Physics Cabinet and the context of their creation is also fundamental. Otherwise, the visitor will get only a fragmented view of what is the Physics Cabinet and we will miss our main objective. To this first message, we should also add some tips on the objectives of the playful experience and its basic rules.

Some changes also relate to Oriverse's platform itself. In the version of the framework we used for the second test, we realized for example that the visitor was overwhelmed by confirmation messages and that feedback should be given to the visitor in a more discrete way. Besides we believe that a clearer distinction between the tips to discover the hidden items and the regular action messages should be inserted in the application.

In addition we can point out some elements that may be investigated further if the project takes shape. For instance, we may get a better idea of the optimal size of the texts, of the pictures and also of the optimal duration of the Cabinet's exploration with a broader test which includes more participants. The design may then be reviewed once more.

Benefits of the QR codes technology

Why do we use the QR codes technology for the playful experience? The QR codes were the suitable solution for the implementation of an indoor project like our playful experience in the Physics Cabinet. Several functionalities of QR codes referred by Mathey in her essay are also or may be useful to our playful experience (Mathey, 2011):

• QR codes are easy to integrate to the already existing exhibition. We believe that this option will not alter the original characteristics of the Physics Cabinet as this is a discrete option and is the most suitable for such an element of cultural heritage;

• QR codes tracking abilities of the system to better know the audience (statistical analysis). By asking the visitor to answer some simple questions in the beginning of the experience (about age and gender) and by tracking the time and sequence of the experience, the museum may be able to reach better its audience;

• QR codes allow to download additional contents in the frame of an exhibition, like, for example, the 3D simulations created earlier for the Physics Cabinet;

• geolocation: when you come close to an item or enter or exit an area, the device automatically receives information, like for example sounds (still to be developed under Oriverse);

• QR codes also allow visitors to let their notes on the object they are seeing (bottom up approach). This could be a way to extend the experience and connect it to the outside;

• links to external contents, for example to other museums that were part of the network in the 18th and 19th century. This could be a way to open up the scope of the experience to an international dimension and then to engage international visitors.

5.4 Evaluating the Design

After this overview of the project "The Science Museum of the University of Coimbra – A Playful Experience", we may conclude that we achieved our main objectives. We indeed designed an interactive experience and turned the visit to the exhibition into a personalized, independent and flexible moment. We consider that we were able to reduce the distance between the objects of the exhibit and the visitor thanks to hypermedia navigation. This new way to explore the Physics Cabinet leads to a synthesis of cultural puzzles that will help the visitor to understand the history of science and the Enlightenment period in Portugal and abroad.

To analyse the design of our playful experience, we will keep in mind why interactive productions may fail. I think that Perrot particularly nailed it when he writes

that among the frequent errors are "*the weak conception of the project and its integration with the museum; under-estimation of the effort needed for making the content; un-reliable technology choices; bad graphics, images or sounds; inappropriate delay for the user to get feedback from the system; and so on*" (Perrot, 1993).

In the last section we presented in details the process and outcomes of the prototyping and playtesting. That's mainly during this phase that we deeply evaluated our design (e.g. adaptation for an indoor utilisation of Oriverse). We indeed decided to go to prototyping only after having gathered all the elements we needed for our experience, in terms of contents but also of structure and technical facility. With the implementation of the project, we can understand if we are on the wrong track and the possible contradictions of the design. If we got a global picture of the experience we wanted to design since the beginning, it got more detailed throughout the process.

The conclusions of the playtesting helped us to improve the Aesthetics route and get this first prototype of the playful experience running under Oriverse's platform. The playtesting allowed us to avoid the main errors referred by Perrot. We decided that we would not extend the tests to stakeholders, experts and members of target audience in the frame of this master work as we had enough elements to conclude this first step, but it may, of course, bring interesting new insights to the possible implementation of the gameplay. In a more advanced state, we believe that the integration of the playful experience in the Museum exhibit is feasible and that it will be pertinent to ensure the follow-up of the visits and of the experimentation of the playful experience, thanks to a questionnaire, namely. How do the visitors interact with the project? Do they follow the routes? Did they engage with the objects? Did they hear/reflect/comment? Is there an appropriation of the contents? What emotions does the experience arouse in the visitor? It seems important to evaluate the fun and teaching aspects of the experience as well as its effectiveness and its accessibility.

5.5 Lessons Learned

With Oriverse's platform and the contents presented in the playful experience, we believe that we reached our objectives and answered the set of questions that we raised in the beginning of the project:

• How do we lead the visitor to the autonomous exploration of the Physics Cabinet?

• What makes a visit outstanding?

• How can we make a visitor interact with an already existing exhibition?

• How do we properly present the objects and the valuable material gathered in the Physics Cabinet?

• How to transmit scientific ideas in a pleasant way?

We have learned how to make the visitor enter the Physics Cabinet of the 18th and 19th centuries thanks to the interactivity of a smartphone application. We did our best to recreate its environment thanks to a sense of narrative and characters which link all the elements and captivate the visitor. Then we may also reflect on the added value of a game for such an experience. Its characteristics enabling the emotional immersion of the visitor and mixing the right balance of fun and serious aspects make us also consider this option as a key element of the project.

In practical terms, we have to enhance the importance of the interaction with the platform's manager to understand the limitations of the existing technology and adapt the project consequently. The relation between IT and contents is really important. Oriverse constitutes a good framework for such a project, despite its indoor limitations. It is particularly good to follow the different phases of the trajectories of interaction. We indeed aim to create a journey exhibition as described by Belaën. The IT and Oriverse are a support to present the scientific concepts beyond the authentic objects. We paid particular attention to guarantee that we were not overshadowing the exhibit by IT solutions.

Another point also oriented our work and is part of our conclusions on the project. What do the visitors retain from their visit to the Physics Cabinet? After several years of existence, the Museum is still facing a double problem: the lack of means and the impossibility to redesign the exhibition as the Physics Cabinet is an historical site of the University of Coimbra. Despite the duration of the project "A playful experience – A new way to explore the Physics Cabinet", the problem is still present. I am of the opinion that a multimedia framework remains the best solution for an autonomous exploration of the Physics Cabinet under the current circumstances.

The implementation of a multimedia application raises some difficulties, but the effort is worth it. One of the main constraints is to find the right balance between the

objectives of the application and its key messages and the limited time that a visitor spends to discover the exhibition. What is the minimum message we want to transmit in the shortest time? What are the duration and the rhythm of a visit to the Physics Cabinet? By dividing the experience in several quests, we think that we allow the visitor to have a quick overview of the main elements we want to point out.

The implementation of a well-articulated sequence of actions and of a strong narrative is hard and time-consuming. Articulating immersion and interaction in our project and avoiding to create a confusing and fragmented experience was harder than we first thought. If we don't pay attention to this aspect, we may lose the attention of the visitor.

With the Physics Cabinet (and most of the augmented reality pervasive game, I assume) we have the constraint of a permanent exhibition that can't be adapted. If we refer to Varano's glossary, the topographic route is not adjustable. The narrative has to fit into this pre-determined frame and it is hard to construct a strong connection that will engage the visitor at least for a medium term. The problem may also lay in the different theoretical approaches we used. It is sometimes hard to conjugate all their key elements (hypermedia narrative, gameplay guidelines, trajectories of interactions, etc.).

We had for example a long hesitation between a "jigsaw-puzzle" and a "shopping-cart" scheme, as referred by Marie-Laure Ryan, for the structure of the playful experience. If we let the visitor exploring the Physics Cabinet at ease, picking an element after the other, without considering any specific routes, we offer him more freedom and total autonomy, but then the reconstruction of the exhibition's message totally lays on the visitor's shoulders. Will the visitor be able to interpret correctly the items he is seeing by him/herself? In some extent, this approach is close to what is currently done by the Physics Cabinet visitors, who have no real guidance to discover the Museum's exhibit. Taking into account that we don't have clear data on the subject, we wonder what the current practices of individual visitors are at the Physics Cabinet and how they could be improved (cf. Wake).

It seems to us that it is also hard to include some difficulty levels and/ or distributed knowledge in such a "disconnected" structure. What we may call "jigsaw-puzzle" - or a reticular structure, to remind Varano´s glossary -, appears to be more interesting for our purpose, but it also raises more constraints, in terms of narrative, as we saw before. Along the design process, we had to re-evaluate the degree of

autonomy we wanted to give to the visitor and had to make some concessions. In our reflection on the most suitable structure for our playful experience, we also had to keep in mind that we couldn't turn the experience into something too complex. The duration of a visit is limited and a too complex organisation may simply prevent the visitor to engage with the experience.

6. Conclusion and perspectives

With the project we described in the previous pages, we think that we designed an on-site product that will allow the Science Museum of the University of Coimbra to captivate and engage the visitors; provide an autonomous discovery of the Physics Cabinet; make the visitor enjoy his/her experience; multiply the number of visitors and draw an interconnected picture of the story of Science.

We have shown along the pages the importance of the gaming concepts, the association of interactivity and immersion, the role of narratives in Virtual Reality and the adaptation of those elements to museums' objectives. Emerging ideas in the frame of trajectories of interaction, pervasive game, augmented reality, mobile learning and technology-enhanced learning led us to our current design.

Yet, we consider that the playful experience in the Physics Cabinet is a work in progress, an open framework whose first steps we just described and which lets windows open. Some of the possibilities we mentioned in this report were not developed yet. We believe for example that a route like the "Conceptual Physics in the Cabinet" could be a good opportunity to put into practice the "being-doing a scientist" that Gee refers in his work to promote effective learning. The evolution of the playful experience will also depend on the available technology.

To be able to implement the project, it may be interesting to study the impact of the insertion of the playful experience in the Museum and University offer, as well as to develop the economical appraisal of this implementation and a communications plan around this new offer. If the result of such an implementation is positive, the Museum can enlarge its offer and open the framework to other collections.

On the other side, we would like to let the door open to an interaction with the social networks to enlarge the visibility of the Museum. The project is made in such a way that you can bring something of your visit, your tokens, with you at home, if you own a smartphone. Those could be easily shared with a large public thanks to the

social media (Facebook, Pinterest, etc.) and would be a way to invite people to discover the museum. We could also allow the user to pin items and explain why they do so. This interactivity is possible thanks to QR codes. Fosh et al. conclude that "participants should be provided with opportunities and resources to tell their own stories from an experience". We think that social media could be a way to materialize stories about the Physics Cabinet.

We believe that another future possibility is to expand the project by adapting it for groups and schools. Designers could make some of the participants/teachers adopt a different role and make them respond to their colleagues'/students' quest(s) instead of the system, for example. This idea is inspired by what Maria Roussou calls the "ultimate interactive process, facilitated by the virtual environment, but contextualized and completed by humans".

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