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**The REVEAL Educational Environmental Narrative Framework for PlayStation VR**

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**Abstract:** The REVEAL project is pioneering the use of PlayStation VR for educational applications which engage audiences in Europe's rich scientific and cultural heritage. The REVEAL software framework facilitates the development of Educational Environmental Narrative (EEN) games in virtual reality for the PlayStation 4. The framework is composed of a set of software layers and editor plugins which augment an existing game engine technology ("The PhyreEngine") and facilitate its transfer to educational applications. The PhyreEngine was created by Sony Interactive Entertainment Europe and is free and open source to registered PlayStation developers, including academic partners under the PlayStation First scheme. The REVEAL framework is built on top of the PhyreEngine and will be made similarly available to PlayStation developers through Sony Interactive Entertainment's developer network.

This paper describes the functionality and design of the REVEAL framework, including its graph-based architecture, node-based locomotion system and high-resolution paper artefact rendering system. Key supporting tools are also described, including the Story Scaffolding Tool and its role in collecting detailed game analytics. The application of the framework is illustrated through an EEN case study application based on the life of Dr. Edward Jenner: the 18th century scientist credited with the discovery of vaccination. Finally, we discuss how we will empirically evaluate the effectiveness of a VR application and its components.

**Keywords:** Game-Based Learning, Virtual Reality, Environmental Narrative Games

## 1. Introduction

The global videogame market was worth an estimated $116.6 billion in 2016 and is expected to reach $143 billion by the end of 2020 (UKIE 2017). This continuing growth is fuelled by advancements in gaming technologies which the mainstream videogame industry is well-equipped to exploit for new business opportunities. However, despite the increasing use of state of-the-art gaming technologies in a wide variety of fields outside of entertainment, technological and economic barriers often prevent the transfer of new gaming technologies to educational markets. One such technology is Sony's PlayStation VR headset, which has quickly become the prevailing head-tracked virtual reality headset of the current generation, exceeding the sales of Oculus Rift and Vive headsets combined (Statista 2018). The central aim of the REVEAL project has been to augment existing free and 'open' technologies for developing mainstream videogames for PlayStation VR, in order to facilitate easier and more cost-effective transfer of Sony's headset to educational applications. As such the REVEAL project specifically addresses the creation of "Educational Environmental Narratives" (EENs) using Sony Computer Entertainment's PhyreEngine platform.

## 2.0. The Educational Potential of Immersive Virtual Reality

The potential for using immersive virtual reality for learning has been the focus of academic research since the term virtual reality was first popularised in the 1990's (Bricken 1991). Research into Educational Virtual Environments has come to encompass both desktop virtual environments and immersive virtual environments using head mounted displays (HMDs). A review of empirical research from 1999-2009 only classified 16/53 studies as immersive, and only twelve of those actually involved virtual reality headsets (Mikropoulos, Natsis 2011). Cost was the main reason cited for the focus on desktop systems, but the launch of the first Oculus development kits in 2013 began a resurgence of research into immersive virtual reality for learning (Lartigue, Cathcart et al. 2014, Casu, Spano et al. 2015, Mathur 2015).

The “learning affordances” of VR environments have been well documented over two decades of research, and include increased motivation and engagement, greater opportunities for experiential learning, richer and more effective collaborative learning, improved contextualisation of learning and enhanced spatial knowledge representation (Dalgarno, Lee 2010, Merchant, Goetz et al. 2014). There is some consensus that the learning proposition offered by virtual reality derives from the technological affordances of ‘representational fidelity’ (including accurate head-tracking, realistic 3D graphics and spatial audio) and ‘learner interaction’ (including embodied actions, embodied communication and control of the environment). These have been hypothesised to lead to a construction of identity, and a sense of presence and co-presence within an environment which underpin the learning affordances listed above (Dalgarno and Lee 2010, p.24).

**2.1. Environmental Narratives**

Environmental Narratives are a relatively new innovation in gaming, exemplified by critically-acclaimed titles like “Dear Esther” (The Chinese Room 2012) and “Everybody’s Gone to the Rapture” (The Chinese Room 2016), but with some similarities to older puzzle games like “Myst” (Cyan Inc. 1993) and “Riven” (Cyan Inc. 1997). They are characterised by rich, high-fidelity environments which are often unpopulated, but scattered with evidence of human activity which relates to the overarching narrative. The narrative is typically communicated through voice-overs or written artefacts which reveal the story in an intriguing, non-linear fashion.

‘Environmental storytelling’ (Smith, Worch 2010) can be employed by games from a range of genres, but represents the core mechanism by which gameplay is achieved in the Environmental Narrative genre. Game designers, Smith and Worch offer a working definition of environmental storytelling as a “staging player-space with environmental properties that can be interpreted as a meaningful whole, furthering the narrative of the game" (2010, p.15). This emphasises the holistic nature of designing Environmental Narrative games, where the environment and story are inextricably linked. They continue to describe four key properties of environmental storytelling (p. 30):

1. Relies on the player to associate disparate elements, interpreting them as a meaningful whole.
2. Fundamentally integrates player perception and active problem solving, which builds investment.
3. Invites interpretation of situations and meaning according to players' views and experience.
4. Can help the player navigate an area by 'telegraphing', i.e. by providing signals to the player.

The motivational affordances of these design properties are suggested as the compelling nature of active constructivist interpretation (1 & 3), the investment of active problem solving through exploration (2), and the innate need to create closure (fill in the gaps) for an incomplete storyline (3). The affordances of telegraphing (4) are a more practical application of environment design (e.g. indications of a previous struggle to alert the player to a potentially imminent danger). In summary they propose that, "Environmental storytelling creates games spaces in which the player is fundamentally invested and immersed in." (p. 34).

Previous work by members of the REVEAL team has suggested that it is advantageous to create intrinsically integrated educational games which have a tight coupling between a game's learning content and its game mechanics (M. J. Habgood, Ainsworth 2011). Smith and Worch's analysis above (2010) would suggest that the core mechanics of Environmental Narratives are already based on constructivist principles of assimilation and accommodation (Piaget 1950). In other words, the Environmental Narrative genre is already a good example of an intrinsically integrated constructivist learning experience (albeit with non-educational goals). Game designers and academics have been drawing parallels between good game design and pedagogical theories for decades (Prensky 2001, Gee 2003, Shaffer 2006, Crawford 1982). Here too the cognitive aspects of an environmental storytelling approach seem to present a particularly promising opportunity for creating effective intrinsically integrated learning environments. This formed the pedagogical rationale for the selection of the Environmental Narrative genre in the REVEAL project.

**2. The REVEAL Software Framework**

The PhyreEngine is a high-performance, cross-platform C++ game engine created by Sony Interactive Entertainment’s Research and Development team. It is free and open source to registered PlayStation developers (including academic partners under the PlayStation First scheme) and includes native support for the PlayStation VR peripheral on the PlayStation 4 console. The REVEAL technologies were designed to extend this existing technology, to provide a higher-level framework for creating Environmental Narrative games for PlayStation VR (educational or otherwise). In combination with the PhyreEngine, REVEAL provides a complete, free solution with no royalty or licensing costs, which is fully compliant with Sony's standards and guidelines. As such, it represents a cost-effective way for game developers and academic researchers to explore new markets in education and cultural heritage for PlayStation consoles.

**2.1 Node-Based Locomotion**

The design of the REVEAL software framework is underpinned by a graph-based approach to navigation and game-logic. This key design decision was influenced by early investigations into to virtual reality locomotion. The REVEAL project seeks to target novice users in educational and museum contexts as well as typical PlayStation users in the home. As such the framework needed to provide a locomotion technique which is simple to use and free from the most extreme effects of motion sickness. This has been achieved through the use of a node-based navigation system which allows the player to move between predefined node positions using a rapid, continuous, linear motion. This technique was developed iteratively and chosen based on the outcome of an empirical evaluation comparing it to other common VR locomotion techniques (J. Habgood, Moore et al. 2018). Contrary to intuition, the evaluation showed that rapid movement speeds reduce players' feelings of motion sickness as compared to continuous movement at normal walking speeds. In the final system, navigation nodes are represented by floating "feet" icons which pulse when the player is pointing their head towards them (figure 2, right). Pressing any button on the controller in this state moves the player to the next node, thus providing a simple single-button VR locomotion technique for REVEAL.

For many VR applications outside of games, node-based locomotion could be considered an unnecessarily restrictive and work-intensive approach, as node placement would typically need to be completed manually. However, the hand-placement of meta-data (such as nodes) within gaming environments is common in game development, and The PhyreEngine's level editor provides built-in support for adding this kind of data (figure 2, left). Furthermore, in the context of many games, reducing the possibility space of exploration and interaction in an environment has a number of benefits. Firstly, it allows the designer to closely direct the path of the player, not only controlling the route they take, but implicitly the precise direction they look at specific points in the game too. This can potentially be used to solve another common design problem in VR games, which is that it is very easy for a player to miss something pertinent because they were looking away at the time. The node-based approach also saves development time and effort by removing the need to provide artwork and user testing for inconsequential parts of the game environment. Finally, there is an additional technical benefit in terms of reducing the software development and processing demands compared to navigation approaches which require real-time collision detection.

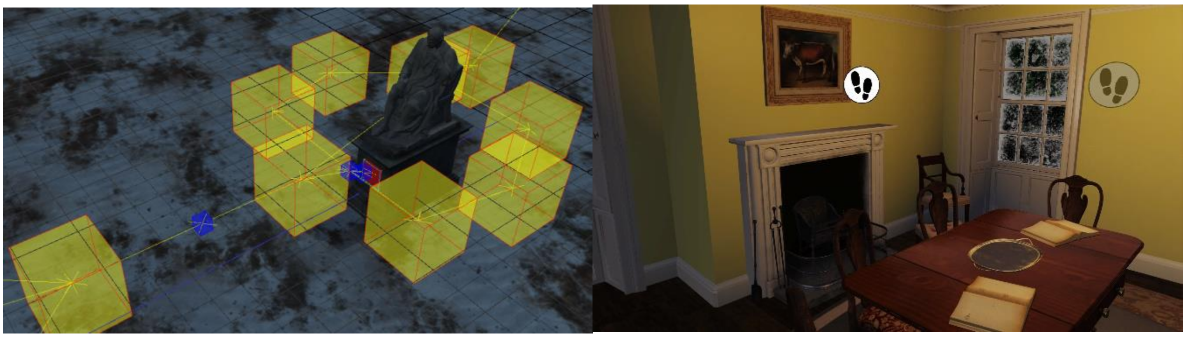

**Figure 1:** Node placement in the PhyreEngine's Level Editor (left) and how they appear in the game (right).

**2.2 Graph-Based Narrative Architecture**

Environmental Narrative games typically only support a relatively simple level of interaction with the environment, and are sometimes even described as "walking simulators" in recognition of this. Nonetheless the narrative content of the game (typically audio streams) needs to be triggered based on the player's current position as well as their previous exploration of other parts of the environment. This may also include some level of basic interaction with objects (e.g. opening doors, examining items etc.). The REVEAL framework provides this kind of simple game-logic through a dependency graph representation of the narrative.

Dependencies in this narrative-graph are linked through logical rules inspired by behaviour trees (Klökner 2013). A set of predefined game events can be used to trigger specific narrative-nodes to be unlocked, which may in turn signal further events. In this way the narrative-graph provides a scripting system for game-logic which allows a player to explore multiple non-linear narrative threads, as well as recording the state of the player's progression within the narrative graph itself.

REVEAL's node-based navigation system also allows interactions to be defined through the spatial-graph. The framework defines four types of spatial nodes: locomotion, somewhere the user may visit; artefact, an object the user may pick-up and examine; trigger, a button or point of interest; and logic, a switching node which controls graph traversal. Through this set of logic nodes, designers can completely control graph traversal, including opening and closing doors, introducing and removing physical barriers, and one-way locomotion. All of these graphs also have the advantage of working well with the gameplay analytics system described later in the paper, and are a key part of the educational evaluation studies planned for the project.

The diagram below (Figure 2) shows a short narrative sequence from "The Chantry" by way of illustrating graph-based interactions using the REVEAL framework. In this section, the player must discover and examine two artefacts, a letter and a county map, to complete an objective labelled "Gloucestershire" before they can progress into a new area. Using the level editor, artefact-nodes are created for each artefact and locomotion-nodes define the positions the player may visit. Edges between these nodes form the spatial-graph. A door is defined through a logic-node (green diamond) within the spatial-graph, and acts as a switch, blocking spatial graph traversal until it is unlocked by a command. Many interactions with the spatial-graph can be made to generate command sequences. Similarly, any narrative-node can generate commands for several conditions (unlock failed, unlock succeeded, already unlocked). Narrative-nodes, shown on the right of the diagram, form part of the narrative graph using dependency rules to govern the players progression through the narrative.

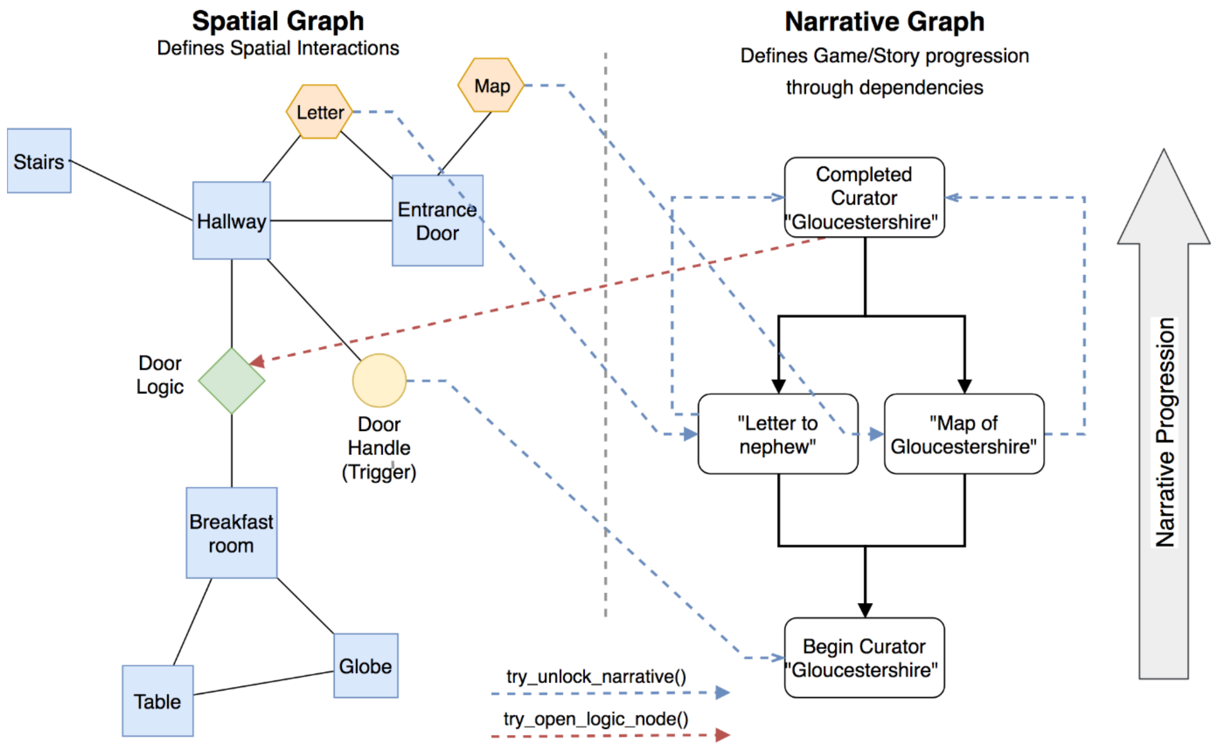


**Figure 2:** In this example, the player unlocks the curator-label narrative by attempting to open the door handle. Once unlocked, this narrative-node allow interactions with both the letter and the map artefacts to succeed in any order. Each player interaction can attempt to mark narrative nodes as complete (try_unlock_narrative commands). Commands in the narrative-nodes can also 'self-unlock'. We see this used for the final narrative-node releases the door logic node back in the spatial-graph. Unlock commands can only succeed if all dependency rules for the target narrative-node are met.

**2.3 Paper Artefact System**

REVEAL's case study projects require a considerable amount of text based artefacts such as letters and documents. Localisation of these text based artefacts would require a large number of textures at readable resolutions. Instead REVEAL's framework renders a complete set of low resolution text artefact textures on initialisation. When an artefact is picked up by a player it renders a single high-resolution texture for readability (see figure 1). This significantly improves the fidelity of written artefacts in VR.

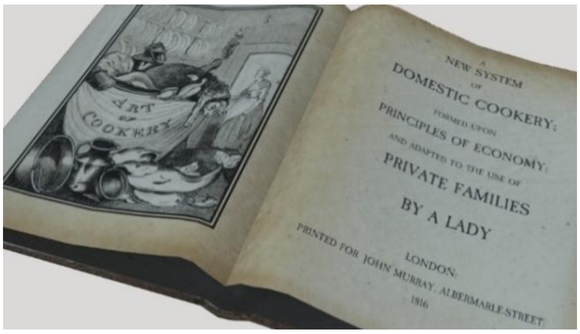

**Figure 3:** A book created with The Paper Artefact System

**2.4 The Storyline Scaffolding Tool**

The story scaffolding tool was created for two purposes: a) to structure the educational content and provide a graphical representation of this and b) to provide an analytical tool for collection and visualization of player interaction data.

**Structuring Educational Content**

A common issue when creating in-game stories is these are traditionally created separately from the actual gameplay, which can lead to discrepancies between the two. Often the in-game stories are created in the beginning of the development process in collaboration with researchers or historians and so on whereas the gameplay itself comes much later and is the result of decisions of developers controlled by their creative, technical and time constraints. To solve the eventual gap where the gameplay and story are not properly aligned, we propose a solution which works on both the story and gameplay at the same time, linking both together so that they are explicitly entwined.

The solution we proposed is based on Story Grammar Theory (e.g. Thorndyke 1977), which defines the structure of a story based on a set of 10 rewrite rules such as, STORY → SETTING + THEME + PLOT + RESOLUTION, SETTING → CHARACTERS + LOCATION + TIME, and subsequently THEME → (EVENTS*) + GOAL, etc. Applying these rules provides the *story graph*, a hierarchical representation with the concrete story information as terminal nodes. By using Story Grammar theory, all of the major story information is represented in a separate story layer and it is possible to visualize the story structure independently of the actual narrative game events. By linking the story to the gameplay, it is possible to see which parts of the story a player has had the opportunity to learn about. In other words, it provides information on the extent in which educational goals are covered by actual narrative game events.

As the narrative graph represents the flow of the narrative events, we can easily use it to track a player's progression through the game. However, the relation between the story and narrative graph also needs to be indicated. Therefore, the tool provides functionality for linking both of these graphs together so that the story information contained in each narrative event and, conversely, the narrative information contained in each story element becomes clear. By showing the story and narrative layer simultaneously and showing links between narrative and story nodes, the completeness of the story in the narrative layer becomes apparent and can be quantitatively expressed. It indicates to what extent the story, and story elements are represented by the narrative (game) elements. If there are many links, it means that a large proportion of the story is covered by the actual narrative elements. This can be judged by counting the number of links between story and narrative nodes and how much of the story was present in the narrative graph, which is referred to as the 'completeness' of the story in the game.

**Game Analytics**

With access to both the narrative graph and story graph data, additional features were able to be integrated into the tool that allow for in-game analytics. One of these is that the tool can track the navigation behavior of players during play by lighting up the nodes that they have visited (see figure 4) and by association, the story elements that they have learned about. In serious games, game analytics is a major focus, as it is beneficial for learning to predict player performance and provide these players with personalized and scaffolded game experiences (Freire, Serrano-Laguna et al. 2016). In addition to the basic 'lighting up' functionality, two measures were adopted from other domains to determine player's navigation behaviour: lostness and sequence similarity. The lostness measure was originally introduced to analyse navigation in hypertext systems (Gwizdka, Spence 2007) However, we hypothesize that these can be used for serious game navigation as well, as navigation is a key issue in game-oriented learning process. Additionally, a sequence similarity measure is included (Musaline, 2012) that has been successful in a range of distinct domains including bioinformatics and music analysis.

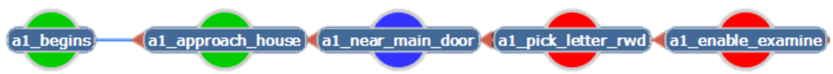


**Figure 4:** Nodes lighting up. Green shows that a node has been unlocked, blue shows that a node can be unlocked and red shows that a node cannot be unlocked.

**Lostness**

Lostness (Smith, 1996) is defined by the number of information items inspected compared with the number of items that need to be inspected to locate the requested information:

$$\sqrt{\left(\frac{N}{S}-1\right)^2+\left(\frac{R}{N}-1\right)^2},$$

*R*, *S*, and *N* are respectively: the minimum number of nodes that need to be visited to complete a task; the total number of nodes visited whilst searching; and the number of different nodes visited whilst searching.

**Needleman-Wunsch Sequence Similarity**

Musaline (2012) is a C++ library for alignment of sequences, which was initially developed for use with musical sequences but, can also be used for comparing other sequences. It makes use of the Needleman-Wunsch (1970) algorithm. To figure out how lost a player is, the path followed by the player is compared with the optimal path. While the lostness measure looks at path length and the number of unique nodes visited, the Needleman-Wunsch algorithm looks at two other aspects, namely:

- Identity, the visited nodes should be identical to nodes in the optimal path.
- Order, the nodes should be visited in the same order as in the optimal path.

Given an optimal path and a player path, the Needleman-Wunsch algorithm efficiently searches through all possible alignments between both paths. An alignment is a list of nodes, where each node represents either a node in the optimal path, the player path or both, such that every node in the original path is represented in the alignment in the order in which they occurred in the original path. A node in an alignment is considered correct if it represents both the player path and the optimal path, otherwise it is considered incorrect. We assign a cost to all incorrect steps and assigning a reward to each correct step. The similarity of an alignment is defined by summing over the costs and rewards for each step. Finally, the similarity of the paths is defined by taking the maximum similarity.

## 3. Applications

The world's scientific and cultural heritage is distributed around the globe, making any single heritage site inaccessible to the vast majority of the world's population. Virtual Reality has the potential to provide physically and economically inclusive experiences which bring users into contact with cultural heritage. In doing so it provides the opportunity to immerse learners in remote and/or historical environments which bring meaning and relevance to their learning. Furthermore, Environmental Narratives bring storytelling and emotion to this experience to aid and promote recall and communication (Mandler, Johnson 1977) and the potential to (literally) see through the eyes of others has exciting implications for communicating a more empathetic and socially responsible understanding of the world (Paiva, Dias et al. 2005) . The REVEAL project includes two case study applications which will use the REVEAL framework to recreate cultural heritage sites in VR. The first of these is now complete and is detailed below in order to provide the reader with an explicit example of the kind of application which can be created with the REVEAL framework.

### 3.1. "The Chantry" and Edward Jenner

"The Chantry" application is based on a virtual reality reconstruction of the Georgian country house of the 18$^{th}$ century English doctor and scientist, Edward Jenner. Dr. Jenner is credited with the discovery of vaccination through his work on smallpox, which eventually led to it becoming the first ever disease to be eradicated (Williams 2010). The game communicates two central "stories" in terms of its learning content: i) the story of Edward Jenner and vaccination; and ii) the story of smallpox and variolation. The first of these is concerned with the life and work of Edward Jenner from 1796 (when he first tested the vaccination process) until his death in 1823, and revolves around the exploration of the virtual reality reconstruction of his family home. The second considers the wider story of smallpox from the height of its effect on European populations in the 1700's to its eventual eradication in 1980. This wider timeline is explored through a graveyard environment external to Edward Jenner's house in order to create an obvious temporal distinction in the game.

The player experiences these two educational storylines through the activities of the player's character, John Hall Hunt. Hunt was the auctioneer responsible for producing the probate inventory for Edward Jenner's house at the time of his death. It is his historical record which has informed the way in which the contents of each room in Edward Jenner's home have been have reconstructed. There is no evidence to suggest that Hunt knew Jenner personally, so he also provides a useful narrative device for naturally uncovering Edward Jenner's life story through the exploration of his home. Further depth is added to Hunt's own story as he ended up in a debtor's prison a few years later, and met an untimely death a not too long after his release.

The game begins in total darkness as the voice of the Reverend Edmund Massey reads from the book of Job. The fate of Job is not only a nod to smallpox, but Massey's sermon was written as an argument against medical attempts to save the masses from smallpox, and sections of it appear throughout the game. This opening section concludes by displaying the name "The Chantry" and the date on which the probate inventory was recorded by Hunt. The player then finds themselves outside a Georgian house with no knowledge of where or even who they are. This information is slowly revealed to the player as they progress through the game and piece the story together for themselves. This constructivist-inspired approach to storytelling is fuelled by deliberately misleading and conflicting information that promotes cognitive conflict. John Hall Hunt's comments sometimes allude to his time in prison, giving the mistaken impression that he may be a thief or burglar. Early sections of the game focus on Jenner's scientific eccentricities and ethically questionable practices, which contrasts completely with the international adulation for him revealed later in the game.

### 3.2. Curation Labels

The primary game mechanic to structure progress in The Chantry game is based around blocking entry to different parts of the house using "curation labels". These keywords 'curate' a selection of objects from the house under a common theme or 'label', providing the player with a narrative anchor around which to group their understanding (and recall) of the story. The typical sequence of events repeated in the game are:

1. The player tries to open a closed door by interacting with the door handle.
2. An introductory voice-over introduces a new *curation thread*.

3. The *curation label* appears on the door (figure 5, left) and the objects associated with completing the thread are displayed in the *thread task list* (figure 5, right).
4. The player finds an object associated with the *thread task list* and examines it to find the *curation label* written on it somewhere.
5. A voice over associated with the object is triggered and the object is ticked off the *thread task list*.
6. Steps 4-5 are repeated until the *thread task list* is complete.
7. The closed door opens providing access to the next area of the game.

In addition, if an object is examined before a thread has been opened, then the player's character comments that the object isn't interesting/useful yet, but the curation label is still visible on the object as a clue to its relevance later in the game.

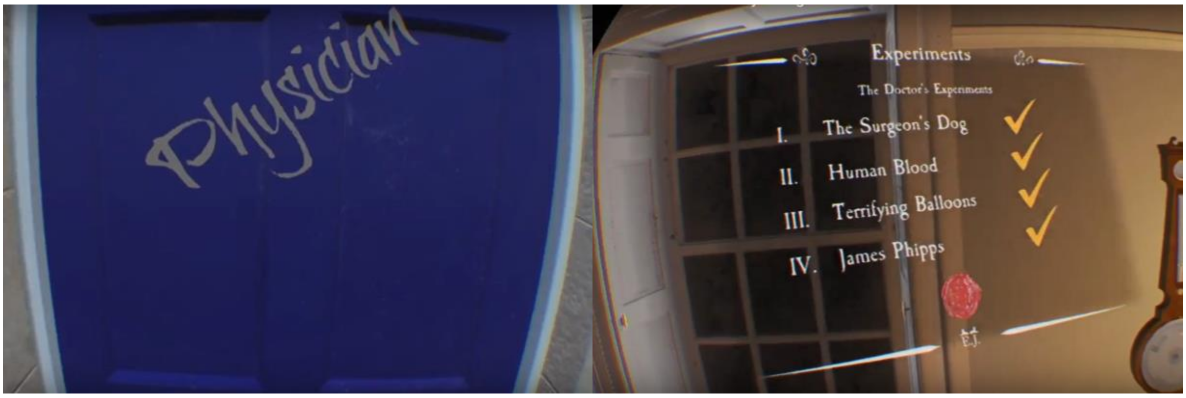


**Figure 5: A curation label (left) and a thread task list (right)**

**4.0. Planned Evaluations**

In a first study, we will examine the main question whether the PlayStation VR application does lead to better learning compared with a traditional, non-VR control condition, using the Chantry game as a case study. Many claims have been made about the affordances of VR games for learning and motivation (Dalgarno, Lee 2010), but the exact empirical results are still scarce and less clear, and our studies aim to clarify this issue. First, we will check whether compared to a traditional, non-VR control condition, the PlayStation VR game leads to better retention of the materials and to a mental representation that is more detailed and includes more accurate spatial information. Secondly, we will investigate the effects of VR games on motivation (Boyle, Connolly et al. 2012, Jennett, Cox et al. 2008). More specifically, we will test whether the PlayStation VR game leads to more engagement, stronger (feeling of) presence, and higher cognitive interest for the subject matter. The main research questions and hypotheses will be examined in a randomized control study. Adolescents and young adults will be individually tested. Learning will be measured by true/false questions of several types on a knowledge test, i.e. conceptual questions and questions involving spatial information. For engagement (Brockmyer, Fox et al. 2009), presence (Schubert 2003) and cognitive interest (Schraw, Bruning et al. 1995) standardized measurements will be used.

In a second study, more fundamental insight will be obtained by examining underlying factors determining the effects of PlayStation VR Environmental Narrative games. The following research questions will be studied by examining two variables that together might be involved: (a) what is the role of typical VR interaction and interactive navigation compared to merely a passive simulation, i.e. navigating through a virtual environment without interactive opportunities, such as a guided tour? (b) what is the role of adding a strong story structure to the simulation, i.e. a virtual environment where the story structure is weaker? These questions will be investigated in a randomized control study with a 2x2 factorial design with the variables interactivity (i.e., interactivity possible or not) and story structure (i.e., story structure strongly present or story structure not-strongly present) so making up four different game versions of the Chantry application. In this study the same measurements as above will be collected. Furthermore, in these studies also the relationship between the gameplay analytics data and learning and motivational aspects as engagement, presence and cognitive interest will be analysed.

**10. Conclusion**

The REVEAL framework provides cost-effective way for game developers and academic researchers to explore new markets in education and cultural heritage for PlayStation consoles. The first of two case study applications created by the project illustrates the use of the framework to create an engaging Educational Environmental Narrative (EEN) game in virtual reality. The empirical evaluation of the EEN VR game will contribute to more insight into its effectiveness, particularly by the analysis of the effectiveness of components of the VR application.

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