VR Serious Game Design Based on Embodied Cognition Theory

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Abstract. Embodied Cognition (EC) theory states that systems for sensing, acting and thinking are intrinsically interdependent and that human cognition is made of modality-specific representations. This approach is based on evolutionary principles of how human beings relate to their environment and for this reason, it is very suitable to be applied to improve design of VR systems, which are clearly based on physical interactions. We can find examples of this theory in common human behaviours as counting with own fingers or walking around an empty room to think about how furniture are going to be placed.

Taking the most contrasted claims of EC, we are going to explore Virtual Reality Serious Games (VRSGs) design from an holistic point of view, trying to optimize the cognitive performance of players. Aiming this, we are going to update Arnab's et al. Learning Mechanics - Game Mechanics model adding VR specific characteristics based on Embodied Cognition theory. This LM-GM model will frame our proposal. Taking as starting point four of the most accepted EC claims, we are going to propose some interaction design guidelines with the objective of improving game mechanics in VRSGs, from a cognitive point of view.

Keywords: Virtual reality · Game design · Serious games · Embodied cognition · Cognitive science · Embodiment

1 Introduction

Over the last few years, we are witnessing a great growing of the integration between two rising disciplines: serious games and virtual reality (VR). This emerging field, VR Serious Games (VRSG) has particular characteristics that are to be analysed in order to push further their use. While using VR as a medium for teaching or training is not a new trend, it is gaining traction since technology is maturing: high resolution and affordable Head Mounted Displays (HMDs), room-scale tracking capabilities or haptic interaction devices have destroyed traditional barriers on VR massive adoption.

The potential of these technologies for training and education was clearly perceived decades ago where some companies started creating first flight simulators, mainly for military aviation [1,2], because they had lower operational costs

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and were safer. With those simulators it was also possible to replicate hazardous situations that could not be reproduced in actual practice. The interface was mainly physical, an exact replica of the controls, so they were not reusable in other trainings, what made them very expensive.

Later, the next field that firmly adopted VR as a learning tool was surgical training. Surgical simulators are complex and eminently physical environments [3], mainly based on haptic feedback. Today they are still one of the most mature examples of the use of VR in a training environment. While it began as a realistic way to simulate certain professional, physical and mechanical processes, if we analyze the reasons for using Virtual Reality in education, we find different motivations. Winn [4] pointed that immersive VR provides first-person non-symbolic experiences that help students in their learning process. These experiences usually cannot be obtained in formal education as regular teaching practice promote symbolic third-person learning experiences. Additionally, other authors as Mantovani [5], focus the benefits of VR applied to education on 'learning in difficult or impossible contexts to be experienced in real life, increased motivation, adaptability and custom educational content creation and great potential as an evaluative tool for its ease to monitoring sessions in the virtual environment'. Recently, in a wide study made by Freina and Ott [6], we see that the most used argument for including VR in the classroom is 'that it gives the opportunity to live and experiment situations that cannot be accessed physically'.

By the time the technological limitations are fading out, researchers and designers have to face new challenges. The most pressing today is to set a sound basis for experience design in VRSG. Game design involves thinking and taking decisions about narrative (what story the game tells with the players' help), aesthetics (how the game looks like) and mechanics (what the player can do inside the game). As we are living the very first moments in commercial VR game design, game companies are "translating" traditional game mechanics and interactions to new VR titles. This approach does not allow to take full advantage of VR inherent capabilities, linked to its immersive and physical characteristics.

In this paper we are going to explore VRSG design from an holistic point of view. As we are going to design games for learning we want to maximize the cognitive performance of players. Along the great number of approaches to cognition we have selected one that fits perfectly with VR nature: embodied cognition, which is based in how our body and its interactions with the environment affect our cognitive activity. For this reason, we want to set a framework to design mechanics and interactions for VRSG supported by embodied cognition theory.

The rest of this document is structured in three parts: First of all we are going to explain the principles of the Learning Mechanics - Game Mechanics model and how it helps game designers to create engaging games that lead players to their instructional goals. We want to update this model, adding VR specific characteristics based on Embodied Cognition theory. The second section is dedicated to give the reader a fast introduction to Embodied Cognition thesis.

In the third section, we are going to analyse the four more documented and studied claims about embodied cognition theory and to link to each of them a number of game design guidelines in order to optimize cognitive performance when developing VRSGs.

2 Game Mechanics for Serious Games

While there exists a clear agreement about the instructional potential of Serious Games, there is not a consensus on how Serious Games have to be designed in order to achieve their dual objective [7]:

1. Serious Games must achieve the transfer of learning to be *Serious*
2. Serious Games must remain engaging and fun to be *Games*

When we design a Serious Game, we must take specially care in the balance of this two components because if we prioritize one over the other we could obtain a boring educational game or a fun game that makes the user to learn nothing [8]. In that sense, if we focus on what makes a game engaging and fun, we should be talking about what the player actually does inside the game: the game mechanics.

The concept of game mechanic has always been accompanied by some semantic confusion, depending on the approach done to explain games. If we refer to the researchers and designers that consider games as a structure with ends and means [9], they use as synonyms the words mechanic and mechanism, defined as 'a process or technique for achieving a result'. Another group of authors, take mechanics as a set of 'rules, player choices and other designs that have been created with intent and consequence in mind' [10]. Additionally, a great number of times, this concept is mentioned but not rigorously defined [7], so we are going to set a pragmatic, working definition for this guide as: A game mechanic represents every single action that a player could chose to do in game and it has actual consequences (interaction) in the game, in the gameplay or in the narrative.

Trying to blend both worlds, instructional and game design, Arnab et al. [7] suggested that: '*high-level pedagogical intents can be translated and implemented through low-level game mechanics...* Serious Game Mechanic *(SGM) defined as the design decision that concretely realizes the transition of a learning practice/goal into a mechanical element of game-play for the sole purpose of play and fun. SGMs act as the game elements/aspects linking pedagogical practices (represented through learning mechanics) to concrete game mechanics directly related to a player's actions'*.

Even when in the work of Arnab et al. they treat dynamics (set of mechanics that, together, contribute to a higher goal or strategy inside the game [11–13]) as mechanics, witch makes their approach a little fuzzy, we are able to take their Learning Mechanic - Game Mechanic (LM-GM) model as an starting point for our proposal. We will use their association of Game Mechanics/Learning Mechanics/Thinking Skills (as they are founded in the digital taxonomy of Anderson et al. [14] to frame our VRSG design recommendations (Fig. 1).

GAME MECHANICS	THINKING SKILLS	LEARNING MECHANICS	LOTS to HOTS
Design/Editing Infinite Game play Ownership Protégé Effect Status Strategy/Planning Tiles/Grids	CREATING	Accountability Ownership Planning Responsibility	
Action Points Assessment Collaboration Communal Discovery Resource Management Game Turns Pareto Optimal Rewards/Penalties Urgent Optimism	EVALUATING	Assessment Collaboration Hypothesis Incentive Motivation Reflect/Discuss	
Feedback Meta-game Realism	ANALYSING	Analyse Experimentation Feedback Identify Observation Shadowing	
Capture/Elimination Competition Cooperation Movement Progression Selecting/Collecting Simulate/Response Time Pressure	APPLYING	Action/Task Competition Cooperation Demonstration Imitation Simulation	
Appointment Cascading Information Questions And Answers Role-play Tutorial	UNDERSTANDING	Objectify Participation Question And Answers Tutorial	
Cut scenes/Story Tokens Virality Behavioural Momentum Pavlovian Interactions Goods/Information	RETENTION	Discover Explore Generalisation Guidance Instruction Repetition	

Fig. 1. Classifications based on Bloom's ORDERED thinking skills, from Arnab's et al. work [7].

3 Embodied Cognition

Different approaches to cognitive science have traditionally treated human mind as an 'abstract information processor, whose connections to the outside world were of little theoretical importance' [15]. In the last two decades, a new movement in cognitive science has raised to 'give the body a central role in shaping the mind' [15]. As we read in Clark [16], *'Biological brains are first and foremost the control systems for biological bodies. Biological bodies move and act in rich real-world surroundings'.*

Traditional approaches to cognitive science, as summarizes Foglia [17], agree about, at least, three fundamental principles that are opposed to the embodiment thesis:

1. 'Information conveyed by a mental representation has no modality-specific features.' That implies that representations are independent from the sensorimotor system and its own characteristics. Embodied cognition defenders think that 'significant differences in embodiment often translate into differences in cognitive processing'.
2. 'Knowledge is represented propositionally, and meaning emerges from the relations among the constituent symbols'. Under embodiment thesis, 'algorithms that constitute cognition sometimes reflect the peculiarities of the physical body'.
3. 'Internal representations instruct the motor system, which is essentially separate and independent of cognition, and so cognitive processing is not significantly limited, constrained or shaped by bodily actions'. In the other side, embodiment thesis is committed with the idea that 'failure to include

information about the body in the description of the mind leads to accounts that are fundamentally misleading and misguided.'

As a global statement of what embodied cognition is, we can say that systems for sensing, acting and thinking are intrinsically interdependent and that human cognition is made of modality-specific representations [17].

We can find examples of this theory in common human behaviours as counting with own fingers or walking around an empty room to think about how furniture are going to be placed.

4 VRSG Design Based on Embodied Cognition Theory

In this section, we are going to analyse the four more documented and studied claims about embodied cognition theory and to link to each of them a number of game design guidelines in order to maximize cognitive performance when developing VRSGs.

4.1 Cognition Is Situated

One of the most relevant and at the same time most controverted statements about embodied cognition is that cognition is situated [15,16]. This represents, in plain English, that cognition occurs in determined place and a moment, in context with some inputs and outputs that affect the cognitive task. Even this argument has dark points because of there are evidently not situated cognitive tasks as imagining or planning, it has an strong evolutionary basis. Before we got civilized, our cognitive abilities mainly serve to our surviving capability and it was clearly related to the environment (obtaining food or avoiding predators).

VRSG Design Guidelines. If we try to exploit this affirmation, we must focus on delivering training in the most similar physical conditions to those where the user is going to apply what he learns. That does not mean that we must invest our efforts on searching photo-realism but we have to reproduce the environment where taught skills are going to be used at a level of detail appropriate to the task we are training to. For example, if we have to design a VRSG for training technicians to repair a high tension generator we not only have to replicate the place, the colours of the buttons or the banners/labels present in the scene but also we have to make the user to pick up a certain tool from a shelf over his head instead of selecting it from a menu.

This introduces new interaction issues such as what happens if the shelf where is stored that tool is two meters tall and user's height is only 1.5 m. It will be impossible that the user would success to pick it up because is out of his viewing range. These situations could represent a bottleneck and alternative approaches have to be designed. Firstly, physical conditions of users and environments affect to interaction in VR so, as designers, we have to pay attention to it.

This guideline could be mainly applied to Understanding, Applying and Analysing levels of the LM-GM model because are more practically related to do some actions in the actual environment.

4.2 Cognition Is Time-Pressured

Embodied cognition theory sets that cognition has to be understood "in terms of how it functions under the pressure of real-time interaction with the environment" [16]. For this reason, we 'should expect some aspects of cognition to be highly reactive and environmentally driven' [18]. This idea of real time processing [19,20] shows us how relevant is embodiment in tasks such walking or swinging, where an incredible amount of inputs are processed in "runtime" to generate appropriated motor outputs.

VRSG Design Guidelines. Time pressure is a traditional game mechanic [7] used to stimulate engagement and motivation. If, additionally, we take in consideration how our cognition works under this circumstances, we must include applying (following Blooms' taxonomy) mechanics with time constraints. In order to make it more effective, we should add some visual, auditive or haptic cues that inform the user about the time remaining. It could be conditioned to different levels of difficulty. For example, in easier levels you have a lot of cues that gradually disappear just to, in final levels, have no cues about timing. Of course, in order to give the necessary relevance to time pressure, it has to have consequences as loosing points, restarting the level, loosing lives or similar.

4.3 We Off-Load Cognitive Work onto the Environment

Our cognitive capacity is limited. Cognitive theory of multimedia learning was stablished by Mayer [21] and exposes that multimedia supports the way that the human brain learns. He, and other cognitive researchers defend that people learn more deeply from words and pictures than from words alone, which is referred to as the multimedia principle. The theory was summarized by Sorden [22] as having the following components: (a) a dual-channel structure of visual and auditory channels, (b) limited processing capacity in memory, (c) three memory stores (sensory, working, long-term), (d) five cognitive processes of selecting, organizing, and integrating (selecting words, selecting images, organizing work, organizing images, and integrating new knowledge with prior knowledge), and theory-grounded and evidence-based multimedia instructional methods. We can simplify this approach focusing on (b), limited processing capacity in memory, and say that if human beings have a certain amount of processing capacity, if we use too much of this capacity trying to interact with the environment, learning the rules, understanding the missions we are supposed to do, reading menus and other activities that often are used in learning environments in VR, we will only have a very small amount of free processing capacity to storage new knowledge.

Embodied cognition theory sets that we off-load some cognitive tasks to reduce our cognitive load. A good example for this is counting with the fingers or how users rotate Tetris block shapes while falling in order to preview where they are going to fit better instead of representing it only in our mind [23].

VRSG Design Guidelines. While cognitive load in VR environments is high due to the novelty of how we perceive the world and how we interact with it, we have to give users the chance to use the environment to simplify cognitive tasks. Using physical tokens to represent some spatial relationships or writing on a wall some intermediate results in a logic problem are examples of how environment and physical interaction could reduce cognitive load in order to obtain a more effective learning. This could be translated into different LM-GM, mainly in the HOTs (Higher Order Thinking) of the Arnab's et al. model as evaluating or creating where learning mechanics as planning or accountability could by matched with game mechanics as design/editing or strategy/planning. In those cases, diagetic previews of what the user is going to build/arrange/set or the possibility to move some items to create physical representations of a problem/task/situation could be a great help. Those items could be from actual blocks to lights or giving the user the capability of drawing on a certain surface.

4.4 The Environment Is Part of the Cognitive System

As we can find in Wilson's summary [15], "the information flow between mind and world is so dense and continuous that for scientists studying the nature of cognitive activity, the mind alone is not a meaningful unit of analysis." This claim could be explained through the extense work of Merleau-Ponty [18,24] about how blinds walking with a cane, they feel the environment not with the hand holding the cane but with the cane. This represents the cane as a port of the body and 'the locus of sensation is extended to the tip of the cane'. Here, the cane is not a tool to obtain data that has to be processed to obtain information about the environment but an artifact that acquire signals and these are immediately interpreted as if they were actually *felt*.

VRSG Design Guidelines. This example of the cane is totally translatable to what users feel when receiving haptic feedback through most popular VR controllers from HTC Vive or Oculus Rift Head Mounted Displays (Fig. 2).

As a great sample of this technique, we can refer to the game "LongBow" included in the "The Lab" experience from Valve. You play the role of an archer situated on a tower of a castle that you have to defend against hordes of enemies. Each time you pull back the bowstring, you can feel an increasing vibration as haptic feedback from the controller you are "holding the arrow". That gives you actual information about how are you performing: if the arrow is properly attached to the string, how strong are you pulling and, in consequence, how far is going to be the arrow thrown... All that information is not processed, is sensed, what permits the player to optimize their cognitive activity.

So, if it is possible, we should add haptic feedback trough controllers vibrations to let the player "sense" different textures, estructures, shapes, strengths, etc. This interaction will apply directly to the Analysing level of the LM-GM model, improving game mechanics as feedback or realism and, consequently, helping learning mechanics as experimentation, feedback, imitation and simulation.

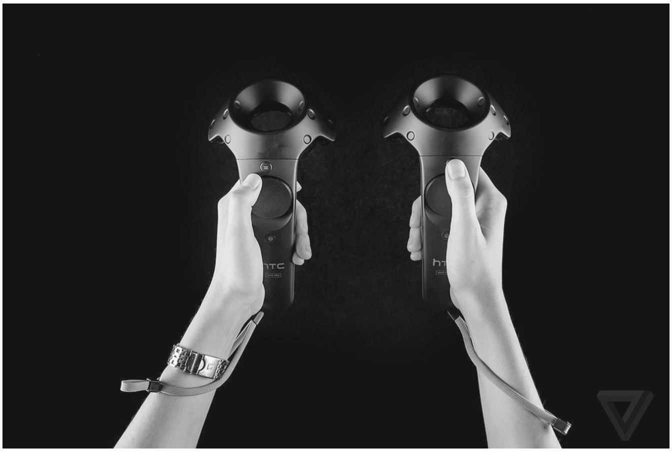

Fig. 2. HTC Vive controllers with haptic feedback

5 Conclusions and Further Work

Embodied cognition is a theory for understanding how our brain works and could give us useful clues about how to better design VR environments for learning. VR and embodiment are intrinsically related and this work wants to reinforce the idea of building VRSG with high levels of interaction because it will improve the senses of presence, immersion and as we exposed before, the cognitive performance of users.

Instructional designers and serious games designers have to rethink how interactions are designed because now, with new VR systems and controllers we have a new range of actions to add to virtual experiences that are "VR native" and not translated from desktop traditional interactions.

Additionally, after analysing how LM-GM model for Serious Games could be updated with some specific design guidelines for Virtual Reality we are totally aware that intense empirical work has to be done to prove that this design framework actually improves the learning experience of users of VRSG. Another area to be developed is the related to how we are going to measure the hypothetical cognitive gain of following Embodied Cognition thesis. As it was highlighted in previous studies [25], there is a sound basis of non-intrusive, physiological metrics as eye tracking to evaluate cognitive load in real time. Now that some new VR Head Mounted Displays incorporate eye tracking capabilities, it's possible to obtain data about cognitive activity of users based on how they look the VR environment.

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