A Study on Teaching and Learning the von Neumann Machine in a 3D Learning Environment

Maria Rosita Cecilia and Giovanni De Gasperis

Abstract The paper presents the design of three serious games for teaching the basis of the von Neumann's machine in a 3D environment. For this objective, the paper initially defines a framework useful to describe the design, then uses the framework to introduce the games. Furthermore, it presents a first prototype of one of the described games. It then describes the protocol that will used to evaluate the usability, proficiency and psychological effectiveness of such games, and ends with a brief discussion on the proposed study.

Keywords Virtual learning environment · Technology enhanced learning · Computer architecture

1 Introduction

Technology-enhanced learning is not a new concept. The use of technology to strengthen the student learning experience is a well established area of interest across all tiers of global education. Educators have always tried to integrate technology into the instruction process. However, innovations in content delivery, assessment methods, and adaptive learning have changed the way in which both teachers educate students and how students learn.

One of the innovations introduced in the TEL field has been the adoption of 3D technologies, as for enabling users to navigate, perform activities, and communicate among themselves at the same time, in a virtual space [1]. Another one has been

M.R. Cecilia
Department of Life, Health and Environmental Sciences, University of L'Aquila, L'Aquila, Italy
e-mail: mariarosita.cecilia@univaq.it

G. De Gasperis(✉)
Department of Information Engineering and Computer Science and Mathematics,
University of L'Aquila, L'Aquila, Italy
e-mail: giovanni.degasperis@univaq.it

M. Caporuscio et al. (eds.), *mis4TEL*,
Advances in Intelligent Systems and Computing 478,
DOI: 10.1007/978-3-319-40165-2_10

the use of games throughout the learning process. Games have recently attracted increasing interest among educators due to the growth of digital gaming in children, teenagers and adults, and also because games facilitate engagement and motivation [2, 3]. Game-Based Learning is an instructional method that incorporates educational content or learning principles into games to engage learners [4]. When games are placed in the context of learning (or training and marketing), they fall into the context of the called "serious games" [5]. Nevertheless, to become a valuable learning experience, serious games must merge a sound theoretical pedagogical underpinning, flanking the classical motivational and engaging aspects of games design.

In such a context, several pedagogical frameworks in a TEL context have been explored, e.g., Situated Learning [6], Problem-Based Learning [7], Experiential Learning [8], as well as many game design frameworks, e.g., EMAPPS [9] and TERENCE [10].

In the paper, we initially present the design of three serious games, developed for a 3D environment, for teaching and learning the basics of the von Neumann machine, for students of the first year of a medical degree and third year of Human Studies. For these games, their pedagogical basis is also discussed (section 2). The paper then continues by presenting the system, the first prototypes (section 3) and the planned experiment in which we aim at evaluating the usability of games and the preliminary foreseen psychological improvements (section 4). The paper then ends with a discussion about the future plans (section 5).

2 Design

2.1 Pedagogical Underpinnings

In recent years, a growing body of scientific studies has focused on the importance of underpinning serious game design and Game-Based Learning strategies with established instructional strategies and pedagogical theories [11]. Accordingly, a serious game design must be unquestionably underpinned by a sound pedagogical framework. In our study, the pedagogical approach is the well-known Problem-Based Learning [7], based on the following key aspects:

1. Knowledge is related to an experiential learning and it develops in response to learners' problem-solving actions [12, 13]. On the other hand, students need to be engaged in doing, rather than passively engaged in receiving knowledge [14].
2. Instruction is a process of supporting knowledge, rather than a process of communicating knowledge; teacher is a tutor instead of expert [12]. The focus shifts from teaching (via didactic instruction) to student learning via active and independent participation in problem-solving activities [15].
3. Learners are engaged in authentic and contextualized problems as near as possible to real life, in order to understand and solve them in a specific contest, and at the same time in order to stimulate and transfer problem-solving behaviors to real-life problems [15, 16].

Table 1 The game framework used in our study

Name	name of the game	
Goal	define what do you want the players to learn	
Instructions	instructions concerning the game, for players: specific to the game instance, motivational, concerning the rules	
Gameplay	**3D Playing field**	describe where the game takes place and what the player sees
	Interaction model	describe how the player interact with the world
	Challenges	describe the rules, obstacles and clues
Mechanics	**Victory condition**	describe how a player wins the game
	Loss condition	describe how a player loses the game
	Progress towards victory	write how the player can understand his/her progress towards the victory
Device	list of all devices available for the game	

Based on Problem-Based Learning Theory, our design strategy proposes different missions which the learner/player must strive to accomplish [17, 18]. Accordingly, the general game can be seen as a complex problem, comprising multiple goals [19, 20]. Each mission requires specific skills: (a) problem definition and formulation; (b) generation of alternative solutions; (c) decision-making, (d) solution implementation and verification [21]. Accordingly, the students will experiment their knowledge via an active and independent participation in problem-solving activities.

2.2 Framework

The subsection focuses on a framework in which we place the design of the three serious games used in our study. The framework starts from the EMAPPS [9] and TERENCE [10] frameworks, and is presented as a table (see Table 1).

Accordingly, in our framework, to design a game we must specify the game name, goal and instruction on how to play to get to the goal. Then, two big section have to be specified. The first is the gameplay, where we specify the playing field, how the player can interact with the objects located in the playing field, and which are the rules, obstacles and clues to win the game. The second section regards the game mechanics, that contains four parts: (i) the internal economy is where we specify who/how the objects are produced/used and the facets for the eventual adaptations, (ii) the victory condition is the exact definition of how a player wins the game, (iii) the loss condition, and (iv) how a player is able to understand his/her progresses towards the victory. A final section is also introduced, regarding the devices that can actually be used to interact with the games.

Table 2 The first game - identify the main components of the von Neumann machine

Name	Pick the computer parts	
Goal	Identification of ideal components of the von Neumann computer architecture	
Instructions	In front of you there are many objects that may be part or not of the well known von Neumann computer architecture. Select the ones that you think are the right ones.	
Gameplay	**3D Playing field**	The island, with buildings, among the many the computer science one. In the building, a first room. It contains a computer and electronics laboratory, with benches, chairs, electronics instrumentations and a set of objects of various electronic gears.
	Interaction model	Touching the objects and show if they are correct or not. Proximity to enable the internal scripts.
	Challenges	Recognize the right parts among a larger set that includes similar and look-like objects.
Mechanics	**Victory condition**	All correct objects are recognized.
	Loss condition	The number of wrong touched objects overwhelms the number of correct ones.
	Progress towards victory	Number of correct object touch events over the total number of right objects. Touching the wrong object reduces the score. Touching the correct object will increase it.
Device	PC, virtual world viewer	

Table 3 The second game: guided assembly: knowing the functions of each component of the von Neumann machine

Name	Build the machine	
Goal	Build the von Neumann architecture in the virtual world	
Instructions	In front of you there are many objects that may be part or not of the well known von Neumann computer architecture. Select the ones that you think are the right ones, and put them in their appropriate component slot.	
Gameplay	**3D Playing field**	The island, with buildings, among the many the computer science one. In the building, a first room. It contains a computer and electronics laboratory, with benches, chairs, electronics instrumentations and a set of movable objects.
	Interaction model	Touching each of the movable objects and touching a destination, the object will move the object in mid air to try to fit the indicated slot. If it does not fit, the object will go back where it started. Proximity to activate the internal scripts.
	Challenges	Recognize the right parts among a larger set that includes similar and look-like objects and how their fit into the final assembly.
Mechanics	**Victory condition**	All slots are filled in with the right components.
	Loss condition	Timeout without filling all the slots.
	Progress towards victory	Number of right object/slot combination over the total number.
Device	PC, virtual world viewer	

Table 4 The third game - interacting with the von Neumann machine: from the components to the general functioning

Name	Engage with the machine	
Goal	Understand how each component relates to the others, how information flows along the von Neumann architecture.	
Instructions	You see if front of you the assembled von Neumann computer architecture. You now have to interact with it by using the text chat, giving commands to each part so that the machine does an actual information processing, letting the information flow through all the components.	
Gameplay	**3D Playing field**	The island, with buildings, among the many the computer science one. In the building, a first room. It contains an almost empty computer room, with science fiction look and feel, with the 3D architecture of the machine in the middle.
	Interaction model	Text chat, touch, proximity position of the avatar.
	Challenges	Giving the right command to each component so that it is able to compute and/or input/output some data.
Mechanics	**Victory condition**	All components have been used at least once to compute a given expression.
	Loss condition	Not being able to give all the commands to the components to compute the given expression before a timeout.
	Progress towards victory	Number of correct commands, number of used components. Result of the computation. How many components are used to compute. The right sequence of activation of components in the CPU read/write cycle. Wrong commands reduce the score.
Device	PC, virtual world viewer	

2.3 Game Instances

In the following subsections, we describe the three games, according to the aforementioned framework.

1. Identify the main components of the von Neumann machine (see table 2)
2. Guided assembly - knowing the functions of each component of the von Neumann machine (see table 3)
3. Interacting with the von Neumann machine: from the components to the general functioning (see table 4)

3 Implementation

3.1 Architecture

The architecture used in our study mainly relies on server-side back-end software processes. The OpenSimulator main process is a MONO C# application that communicates with the client side virtual world viewer through a openmetaverse protocol over HTTP/UDP, as in [22]. It also uses the SQL server process as persistence memory of the world objects and properties, including internal objects scripts. Some of those scripts contains the games' logic and gateways to the redis event server that constitutes the adaptive system memory. The player is only using the virtual world viewer, among one of the existing open source package (FireStorm, Singularity or KoKua viewers) that encapsulates all the rendering, 3D data and interaction events.

3.2 Prototype

A prototype of game number 3 “Engage with the machine" has been implemented as reported by [22], upgraded with the redis server and its related LSL scripts as adaptive engine. In particular the LSL redis scripts log all the user activity triggered by the events of game interest (touch, chat, proximity). It also updates redis sets with abstract items representing achieved results so that the score can be easily calculated with cardinality of those sets. Few screenshots are available in Figure 1.

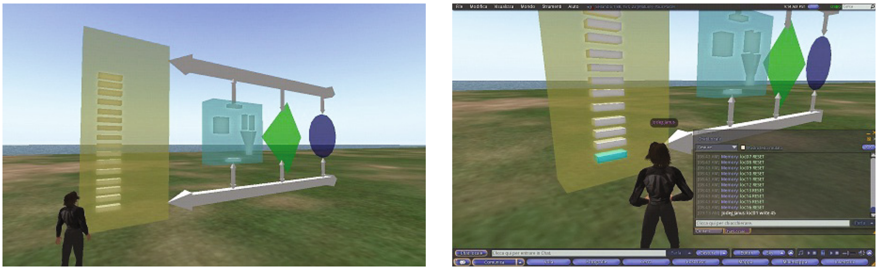

Fig. 1 Screenshots of the prototype

4 Evaluation

4.1 Experiment Design

The design of the experiment is a transversal study, for exploratory purpose, i.e., an observational study in which the exposure to a specific factor (i.e., the gaming activity) and condition (i.e. problem-solving skills) is determined at the same point in time in an exposed population wrt a control [23].

The aim of our study is threefold. First, to evaluate the pedagogical effectiveness of the system. Second to explore the psychological effectiveness of the system. Third, to assess the system usability. This leads to three corresponding research hypotheses. After the usage of the system the expected result shall be:

1. As for the pedagogical viewpoint, an improvement of the learners’ proficiency;
2. As for the psychological viewpoint, a positive change in students’ strategic knowledge and in their emotional attitude,
3. As for the usability viewpoint, an engagement of students giving feedback about the overall game playability

The preliminary results will allow us to understand how to improve our games.

The following subsection describes the details of the experiment in which the usability and psycho-pedagogical effectiveness will be evaluated.

4.2 Procedures

Potential participants will be students from the University of L'Aquila, attending the first year of Medicine and Surgery degree course and the third year of Philosophy and Communication Theory Processes degree course. The experiment is depicted in Figure 2.

In the first part of the study, all students will be divided into two groups respective to their courses, i.e. the Health Informatics course at the Medical School and Foundation of Computer Science course in Human Studies, concerning the basic knowledge of the von Neumann machine. It is worth noting that this part of experiment is already completed: all students took a 2h course unit on the basics of von Neumann machine during the month of November 2015. The second part of the experiment will be presented as a supplementary didactic activity, organized as follows. The games will be shown by the teacher that will explain how to interact with them. All participants will be randomly assigned to either Group 1 (G1) or Group 2 (G2). In a first step, only G1 will play with the games. The time for the students to complete all games will be at least 5 hours, which are needed to become acquainted with the 3D environment, move within the playing field, interact with the objects disseminated in the 3D world, and solve the puzzles that represent the final goals of the games. In a second step, both G1 and G2 will complete the proficiency and psychological tests, described in 4.2.1 and 4.2.2 respectively. It should take about 1 hour. In a third step, only G1 will perform the UX tests, while G2 will use the software. At the end of learning activity, also G2 will complete the UX tests described in Section 4.2.3.

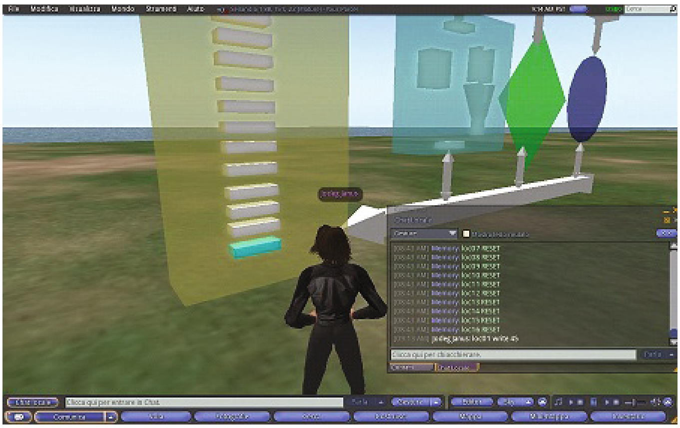

Fig. 2 The experiment

The pedagogical, psychological and usability goals, as well as the outcome to assess are discussed separately. This distinction increases clarity, and therefore better comprehension about the related research findings.

Examine Students' Proficiency (Pedagogical Outcome). As described above, from the pedagogical viewpoint, the expected result will be the improvement of the learners' proficiency, i.e., the students' learning achievements about the principles of von Neumann machine after the usage of system. An Ad-Hoc Achievement Test will be used to measure students' achievement in learning. It will be developed based on the content of Informatics course by two experienced teachers in this field. In particular, this test will be used to assess the students' knowledge on von Neumann machine. We will evaluate proficiency comparing skill-based learning outcomes of G1 and G2 during the second step, when only G1 will have played with the games. More precisely, we will examine differences in proficiency between a group of students who will use the system (G1) vs. a group of learners who will not (G2), on a Ad-Hoc measure of academic competence about the principles of von Neumann machine. The expected outcome is that G1 will have higher scores than G2.

Examine Students' Strategic Knowledge (the First Psychological Outcome). As for the psychological viewpoint, the expected result will be a positive changes in students' strategic knowledge, i.e. the learners' study strategies and in their approach to study. Strategies may be defined as "goal-directed operations employed to facilitate task performance" [24]. Strategies are strongly related to problem-solving skills, e.g. they allow generating solutions to problems, they are potentially conscious and controllable, but they can be also automatic [25].The Study Strategies Questionnaire will analyze students' beliefs about a specific strategy (functional or dysfunctional for learning, e.g. mapping or diagrams to draw connections and show relationships between idea; make summary notes on the important concepts; integrate new information and knowledge; etc.) and its actual use. The Approach to Study Questionnaire will give information on students' working method and their approach to the study, in particular, their ability of organization, processing, self-evaluation, preparation for a test and metacognitive sensitivity. These questionnaires are part of Abilities and Motivation to Study Battery [26]. We will evaluate strategic knowledge comparing cognitive and metacognitive outcomes of G1 and G2 during the second step, when only G1 will have played with the games. More precisely, we will examine differences in strategic knowledge between a group of students who will use the system (G1) vs. a group of learners who will not (G2), on specific measure of strategic knowledge. The expected outcome is that G1 will have higher scores than G2. However, considering the specific characteristics of strategic knowledge, we do not expect significant differences between G1 and G2.

Examine Students' Emotional Attitude (the Second Psychological Outcome). We will evaluate emotional attitude comparing levels of self-efficacy, anxiety and resilience of G1 and G2 during the second step, when only G1 will have played with the games. Self-efficacy determines what activities people participate in, how much effort they will invest, how long they will persist to over-come challenging situations [27]. On the other hand, anxiety [28] and resilience[29] are critical to academic success. The Anxiety and Resilience Questionnaire will investigate emotional attitude toward their academic failure and success. This questionnaire is part of Abilities and Motivation to Study battery [26]. The General Self-Efficacy Scale, Italian version by Sibilia et al., [30], will evaluate students' belief in their ability to complete tasks and reach goals. Emotional attitude is not directly related to problem-solving skills, but it influences how the learners approach a problem. So the expected outcome will be that G1 will have higher scores than G2 about self-efficacy and resilience and lower about anxiety. However, considering the indirect relation with problem-solving strategies, we do not expect significant differences between G1 and G2.

Examine the Usability of the System. As for the usability, we will follow a quantitative approach [31], i.e., a set of UX metrics like the single ease question, time on task and System Usability Scale [32],which are easy to submit and fast to be collected. Student interactions events are recorded via a centralized log server that stores timestamps generated from the virtual world while students interact with virtual objects, such as proximity, click, chat and collision events.

In summary, the following research question will be explored:

– Examine differences in

1. Skill-based learning outcome of both G1 and G2
2. Cognitive and metacognitive learning outcomes of G1 vs G2
3. Affective learning outcomes of G1 vs G2

– Examine the usability of the system in all groups

5 Discussion

The paper presented a study in the threefold context of TEL, 3D and games. It presented the design, a first prototype and the proposed experiment to assess the effectiveness of our approach. The research group will focus in the coming years to introduce a general purpose 3D training session editor based on UML like MASCARET [33]. The motivations are twofold: (i) it already produces Unity learning objects suitable for mobile devices, (ii) in future it could also be integrating OpenSimulator since the base code is C#.

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