Computers & Education 62 (2013) 231–248

Contents lists available at SciVerse ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

A model supported interactive virtual environment for natural resource sharing in environmental education

N. Barbalios [a,*], I. Ioannidou [c], P. Tzionas [b], S. Paraskeuopoulos [a]

[a] Dept. of Special Education, University of Thessaly, GR 38221, Volos, Greece
[b] Dept. of Automation, Alexander Technological Educational Institute of Thessaloniki, GR 54101, Greece
[c] Dept. of Early Education and Childhood Care, Alexander Technological Educational Institute of Thessaloniki, GR 54101, Greece

ARTICLE INFO

Article history:
Received 11 April 2012
Received in revised form
21 October 2012
Accepted 26 October 2012

Keywords:
Multi-agent modelling
Natural resource sharing
Human computer interaction
Virtual environment

ABSTRACT

This paper introduces a realistic 3D model supported virtual environment for environmental education, that highlights the importance of water resource sharing by focusing on the tragedy of the commons dilemma. The proposed virtual environment entails simulations that are controlled by a multi-agent simulation model of a real ecosystem consisting of a lake that is being drained by a community of farmers with different types of behaviours. This resembles real-life scenarios, where farmers operate under extreme economic pressure. The virtual environment provides realistic visualization of the elements of the multi-agent model in a comprehensible manner, while keeping the details and the complexity of the ecosystem hidden from the students. Extensive experiments were conducted using students divided in a control group, exposed to conventional teaching means, and an experimental group that used the proposed virtual environment. Both groups were administered questionnaires at pre-test and post-test intervals, and conclusions were drawn after qualitative and quantitative analysis of the results. It was revealed that the proposed virtual environment provided significant cognitive advancements for the students, especially for complex inter-related notions, thus constituting a valuable tool for environment education.

1. Introduction

Over the past decades, much attention has been drawn on the study of the environment and the sustainability of the earth's ecosystems. Although laws have been legislated to regulate human activities in order to reduce harmful effects on natural resources, great effort is given in changing the people's perception about the value of nature and the impact of the earth's limited resources in their everyday life. Such a systematic effort comes from environmental education that is usually included in the curricula of most educational systems in the world (Strokes et al., 2001). Environmental education aims at the study of natural processes and the development of skills and attitudes towards the sustainability and the protection of the environment (Strokes et al., 2001).

A means of studying ecosystems and natural processes are environmental models, that focus either on the natural process itself or on an entire ecosystem, including the socio-economical parameters and the human - environment interactions it entails. Ecosystems, however, are complex systems that are not easily mathematically formulated since they are dynamic both in time and space, and they have multiple states and multiple equilibria (Ioannidou et al., 2003). As a result, the mathematical models used to describe them are usually too sophisticated and complex to be used for environmental education, especially for primary school students (Bain et al., 2000). Moreover, in some cases it is too difficult to construct accurate models of ecosystems using plain analytical methods, due to their complexity (Muller et al., 2000) and the inter-dependence of their elements (Tzionas et al., 2004), thus a more systemic approach is required. A popular approach for modelling and simulating ecosystems that overcomes such complexity issues are Multi-Agent Simulation (MAS) models. They consist of numerous autonomous interacting agents that mimic actual behaviours of the real world, allowing the direct representation of individuals, behaviours and their interactions (Ferber, 1999). They provide a bottom up approach in ecosystem modelling that gives more emphasis in

* Corresponding author.
E-mail addresses: nbarba@autom.teithe.gr (N. Barbalios), irini@bc.teithe.gr (I. Ioannidou), ptzionas@autom.teithe.gr (P. Tzionas), pstefano@uth.gr (S. Paraskeuopoulos).

0360-1315/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compedu.2012.10.029

the decision making process and the social organization of the agents (Bousquet and Le Page, 2004; Shoham and Leyton-Brown, 2009), and they have been successfully used by many researchers as tools for natural resource management (Bousquet and Le Page, 2004).

In the context of this paper, we propose the use of such a MAS model for environmental education, in order to highlight the importance of water resources, reveal the problems arising when multiple users of a water resource over-exploit that resource for self-lucrative reasons leading to its depletion (i.e. tragedy of the commons dilemma (Deadman, 1999; Hardin, 1968)), and demonstrate a solution to that problem. In more detail, we introduce a novel interactive virtual environment that serves as a high-end layer for a MAS model, visualizing its elements in a comprehensible manner. In this sense, the realism and scientific accuracy of the simulation is guaranteed by the MAS model, while the mathematical complexity of the ecosystem dynamics is hidden from the students. This is a significant advancement compared to most educational virtual environments proposed in the literature, which are based on abstract assumptions and modelling simplifications about the underlying environmental processes (e.g. (Fan et al., 2010; Mikropoulos et al., 1998; Mikropoulos and Natsis, 2011)). In more detail, with the aid of the MAS model that accurately replicates the situations of a real life ecosystem (Barbalios et al., 2012), the proposed virtual environment educates students on real world scenarios avoiding misconceptions that might occur otherwise. The proposed virtual environment visualizes water sharing scenarios, where a water resource is drained by a community of farmers under various behaviours, and highlights the environmental and socio-economical impact of each behaviour. Additionally, a novel machine learning algorithm that is embedded in the MAS model may be used as a water regulatory policy, thus equipping the virtual environment with the capability of investigating water sharing scenarios where the farmer's actions are self-regulated towards a more environmental friendly attitude. In this sense, the proposed virtual environment also emphasizes on the manner water regulatory policies can be imposed to achieve efficient resource allocation.

The development of such a virtual environment is motivated by the pedagogical goals set in the analytical programs of Greek primary schools. Although a multitude of graphical environments exist for other disciplines, such as mathematics and physics (Dimitrakopoulou and Komis, 2003; Panagiotakopoulos and Ioannidis, 2002), very few similar environments exist for environmental education. As a result, environmental education is limited to textbooks and class activities, without providing the students a first hand experience of natural processes and notions related to the environment. Moreover, the concept of an ecosystem is sparingly defined in the images of nature encoded in textbooks of Greek primary schools (Korfiatis et al., 2004). Using the proposed virtual environment, students are immersed in a virtual world and acquire knowledge and first hand experiences about a natural process (i.e. water sharing).

The proposed virtual environment was constructed in successive stages and with the active participation of students. From a pedagogical point of view, this approach is in accordance with the principles of constructivism theory, allowing students to construct internal representations of knowledge (Burdea and Coiffet, 2003; Kettanurak et al., 2001). During the design of the virtual environment, 14 students successively evaluated the design requirements of the environment with respect to the clarity of the graphical representations, the usability and interaction with the interface and the comprehension of the simulation procedure. The student's observations were taken under consideration, modifying the virtual environment to it's final form, used in this study. Subsequently, the learning advancement provided by the proposed virtual environment was investigated, using an experimental group of 24 primary school students. Extensive experiments were conducted, comparing the cognitive advancement provided by the proposed virtual environment to that of a typical environmental class and promising results were derived after a qualitative and quantitative analysis at post-test and pre-test intervals. Thus it is argued that the proposed virtual environment serves as a valuable tool for environmental education.

1.1. Related studies: interactive graphical environments and learning

Interactive learning environments are interactive educational software with the purpose to facilitate teaching and support learning, by taking advantage of computer capabilities, such as simulation, visualization or feedback. They constitute a popular teaching approach, since they achieve easier learning, better understanding and make the learning process a pleasant experience (Scaife and Rogers, 2001). Moreover, there is a growing research base indicating that students learn more deeply from well designed multimedia learning environments than from traditional verbal - only messages (Mayer, 2003).

Recent advances in computer science (e.g. authoring software, hardware that supports realtime 3D rendering) initiated the development of 3D virtual environments, which are computer simulated 3D worlds simulating the user's physical presence in them (Burdea and Coiffet, 2003). In this sense, students are immersed in environments that would normally be unavailable to them, due to cost, safety or perception restrictions (Fan et al., 2010), obtaining first person experiences about the simulated world. Additionally, the immersion that 3D environments provide is highly motivating, encouraging users to spend more time on a given activity (Scaife and Rogers, 2001). From an explicit pedagogical perspective, they create distinct learning experiences for students, assisting them in clarifying aspects of a scientific explanation that are not apparent when that explanation is given in a mathematical or linguistic way (Ioannidou et al., 2003). Additionally, as students navigate in the virtual word, they enhance their learning and improve knowledge retention through interaction, repetition and one to one experimentation (Burdea and Coiffet, 2003; Scaife and Rogers, 2001). Furthermore, having access to multiple representation through multimodal interaction is also assumed to aid learning of abstract concepts (Scaife and Rogers, 2001).

Virtual environments have been extensivelly used as an educational tool across all disciplines. A considerable review of educational virtual environments can be found in (Burdea and Coiffet, 2003; Hew and Cheung, 2010; Mikropoulos and Natsis, 2011). In the context of environmental education, virtual environments provide a significant advantage over traditional teaching methods, mainly because they allow students to have experiences not available to them in the physical world (Taylor and Disinger, 2008). A virtual field laboratory is presented in (Ramasundaram et al., 2005), that gives students the ability to study environmental properties and dynamic processes occurring in a real field (like water flow), whereas in (Okada et al., 2001) a collaborative environment is presented where students and experts communicate and retain knowledge through VRML models of inaccessible natural environments. In a similar context, virtual environments simulating the natural phenomena of lake eutrophication are introduced in (Fan et al., 2010; Mikropoulos et al., 1998), whereas in (Huang and Claramunt, 2004) a virtual environment is presented for visualizing the behaviour of a topography based hydrological model. Virtual environments can also provide to students the ability to act on the virtual world and observe the impact of their actions. This is the case in (Ioannidou et al., 2003), where a virtual environment is introduced that makes use of fuzzy inference to create a lake model for demonstrating the environmental stressors of an ecosystem. The accuracy and realism degree of virtual environments is