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Using educational adventure-style game as a teaching method in a specific engineering domain

S. R. Zheleva[1], A. Amory[2], T. K. Zhelev[3]
[1]*Department of Computer Studies, Durban Institute of Technology, South Africa.*
[2]*Centre for Information Technology in Higher Education, University of Natal, Durban, South Africa.*
[3]*Department of Chemical Engineering, University of Durban-Westville, South Africa.*

Abstract

In a world of accelerated change in technologies and education, due to the impact of globalisation and the information and communication revolutions, the world-wide demand for easier and flexible learning can only be achieved through meaningful reforms and innovations in teaching/learning practices at Higher Education (HE) institutions. One possible solution to the problem that, perhaps, may become the gateway for success, is the use of interactive multimedia technologies together with a sound educational methodology.

This paper discusses the application of multimedia game-based technology in the process of teaching/learning on a specific engineering domain. It reports on a component of the Virtual Learning Spaces (VLS) project designed as an adventure-style three-dimensional (3D) desktop educational tool. The project is supported by the Department of Arts, Culture, Science and Technology of the South African government. The component, or portal, "Africa as Technology Creator" reported here, attempts to promote understanding of a unique local technology for liquid fuel production from solid fossil, and familiarise learners with a recognised technology for energy savings and water/wastewater minimisation, based on integration of processes and systematic resources management procedures.

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1 Introduction

"It is not necessary to read tea leaves, talk to Gods, or conduct complex equations to understand that educational system will have to change. As computer-related technologies penetrate every aspect of society, and education becomes a priced commodity, educational institutions will have to break with tradition, to respond to the demand for more and better education. We know that the future of technology is limitless due to human intelligence and innovation. But will the future of education continue to be limited due to human tradition and inertia?"

Sonia Jurich [1]

To respond meaningfully to the challenges of the 21st century, the HE institutions need to embrace new teaching and learning models to transform themselves by instilling best practice in their programmes. Information and Communication technologies (ICTs) may enhance the teaching/learning process by reinforcing the content provided in traditional ways and may be useful in developing new means of instructional delivery that will cater for different individuals' learning needs through variety of learning styles. While technology can help learners do things that may have been impossible earlier, and motivate them to learn through authentic and multi-sensorial learning activities, the learning technologies themselves do not automatically improve the educational process – they are only tools. However, it has often been argued that the proper use of ICT in constructivist learning environments will improve the quality of learning.

2 Virtual reality in educational practice

Technology enhanced education opens new avenues for learning and skills development and may prepare individuals to function efficiently in today's technology-driven society. But the use of ICTs should be in ways to ensure that learning is meaningful, connected to the learners' interests and understanding of the world, and caters to a range of learning styles and levels of intelligence. With the advent of the World Wide Web (WWW) whole new worlds of interactive virtual environments have been developed. Since WWW is an interactive medium, this has created a new cognitive environment called hyperspace, and a new social environment, called cyberspace. In hyperspace information is stored, manipulated and retrieved in new ways as opposed to traditional text sources, whereas in cyberspace an interaction of cognition of individuals occurs [2].

Recently, a number of Virtual Environments (VEs) has been developed for educational purposes [3,4,5,6,7]. They are particularly useful when the learning domain is complex, abstract in nature and difficult to master, and when the virtual features of the learning environment are critical to the success of the learning process. Since the real-world experience is multi-sensorial, Furness [8] argues that the learning environment should replicate all these sensations. VEs should provide a close physical resemblance to the real world, immediate feedback, and strong sense of learner's presence. They should also reflect on the

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relationship between changing situation during learning process and the learner's goal. To achieve both learner's presence and reflection in the learning process, such virtual environments suggest constructive knowledge and cognitive learning. Such spaces provide enjoyable and entertaining experiences that entice curiosity, stimulate attention and motivate for learning. Since virtual education should not be "a poor replica of the conventional methods", it should use the potential of multimedia educational technology to animate, simulate and capture reality, and "do traditional things in new exciting ways" [9]. Learning technologies should also be aligned with sound pedagogy and instructional design. One of the most important strengths of VEs as teaching/learning tool is the sense of the learner's presence in the environment through a feeling of "immersion in the virtual experience". The knowledge acquired in such experience is argued by Kalawsky [10] to be transferred as knowledge into the real world. According to Romano and Brna [3] the sense of presence in the VE is necessary to create a first-person recallable and useful experience. To trigger presence and provide a sensory input similar to that in the real world, usually a three-dimensional (3-D) high resolution graphics and audio are used in a game environment. The 3-D nature of exploration improve the spatial memory, thereby the information gained from the VE does transfer directly to an equivalent real environment.

In multimedia virtual environments the sense of presence is enhanced through added visual dimension that suggests movement and physicality – something that is not found in text-only environments and has a great impact on human interaction and communication [11]. In this case, users have not only verbal mode for communication at their disposal, but also a non-verbal behaviour, which makes a greater psychological impact on the learning process. They are allowed to express their identity visually, by means of avatars, rather just through written words. (The word avatar means 'reincarnation' and comes from Indian culture; in a VE an avatar is a computer-graphics representation of a person.) The avatar is enabling people to maintain partial anonymity. Partial, since the visual characteristics of the avatars highlight aspects of self, of personality and lifestyle – who you are, or who you wish to be. This is very much a process of playing to explore identity. Such a play is realised in 3-D Collaborative Virtual Environments (CVEs), also called "Virtual Reality" (VR), that foster communication and interaction among the social actors (rather then the user-computer interaction). The play is in specific context, built around a real, concrete situation [7]. Rieber [12] describes play as an important element in human psychological, social and intellectual development, as intrinsically motivating and pleasurable activity that is independent of external rewards. He argues that microworlds, simulations and games are the three learning environments consistent with play, which mediate interactivity. Game is a particular structured form of play where fantasy, curiosity, challenge and control, as intrinsic motivations for learning, are met. Playing a game successfully requires engagement of critical thinking and problem solving skills in understanding the game concept.

Story plays an essential role in each game by presenting players with a problem to resolve a mystery. Game story line (or cover story) employs fantasies and challenges, which stimulates the curiosity of learners [13]. Cover

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story may be used to guide learner's interactions [14]. It may be based on metaphors and analogies as powerful techniques to provide contexts for interactive experiences and help players make sense of unfamiliar situations. Furthermore, an appropriate story line in educational decision-making games might be used to encourage the creation of learner-generated analogies. In such games the learner usually is placed in a unique situation to achieve a goal within the analogous cover story. The way players apply the knowledge of what they have been learning (i.e. how they achieve the learning objectives) determines the outcomes of the game (i.e. what game objectives have been achieved). The use of analogies and metaphors in the educational games is an instrument to provide meaningful context for implementing what is being learned. Analogies and metaphors are means of integrating new information with prior knowledge to produce deeper comprehension. The learner's interactions in the VR are real, as they deal with concrete tasks on relevant topics of a real context, which has a tangible output in the real life. As far as virtuality is concerned, it deals with the fact that the experience of these interactions is not placed in the real world, and the community which is built during the play, perhaps, may not be possible in the real world due to spatial, social, and other constraints. This just confirms the opinion of Talamo and Ligorio [7] that "when an interactive virtual context is built around a real and concrete situation, the blur between the real and virtual resources, offered by the cyberspace, gets more evident". Turkle [15, p.153] summarised, "virtual reality becomes a play space for thinking about the real world".

3 The "Virtual Learning Spaces" game and its portal "Africa as technology creator" (Work in progress)

The use of educational game technology aligned to the modern information and communication systems, together with constructivist learning theory, provides viable opportunity for the development of the Virtual Learning Spaces project [16]. The project includes several content areas, each conceived as a microworld (small, but complete subset of reality) and defined as a specific knowledge domain within the large game, where players become part of the scenario, rather then passive learners of a particular domain.

The game falls in the category of educational 3-D desktop adventure-style virtual reality, the development of which involves input from researchers, educators, graphic designers, programmers and postgraduate students. The main goal of the game is to set a community of learners and practice able to construct a collaborative knowledge on the specified game domains through interactions and communications in the virtual environment. The game content areas, design and technology have been previously described [16]. Several communication tools (text-, voice- and visual-based, synchronous and asynchronous), and interactive objects are embedded into this virtual reality. The technology used in the game includes "point-&-pick" and 360° panoramic environment that employs both first- and third-person views. Panoramic views provide players with better orientation in the virtual environment. First-person perspective allows players to interact directly with the game objects, while with the third-person views players become part of the virtual space (as avatars), and may assume a particular role

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and interact with one another. Learners are free to choose any avatar to whom they may assign specific characteristics (race, gender, hair and clothes colour and style), and change them at any new session, or even during the same session. Thus, each avatar reflects a distinct aspect of the individual's personality and lifestyle. Learner's collection of avatars is a balance between new and old persona, between the process of experimenting with new identities and holding onto the familiar, stable aspects of the self. Players can create and change their identities by means of a Character Editor, specially developed for this purpose. Another tool created for the game is the Scenario Editor. It enables transformation of the background bitmaps into interactive scenes of the game, and addition of respective scene objects like hot spots, images, movie clips, walk areas, etc. It also provides means for navigation between the scenes. Other tools and objects embedded in the game virtual environment include game own browser, HTML editor, e-mail client, Help Agent, photo album, and virtual cell phone with voice component for synchronous communications.

The game design model, created by Amory, is reported in [17, 18]. It is based on Object Oriented and Software Engineering methodologies. In order to integrate sound educational theory, game design, play and development it includes three base models: Game Object Model (GOM), Persona Outlining Model (POM), and Game Achievement Model (GAM). While GOM and POM take care of the game and persona conceptual design components (object classes), which are combination of both data structure and behaviour, and accommodate either abstract or concrete interfaces, they themselves are not sufficient to conceptualise the game story line and fit it into the game framework. This situation called for the development of GAM by means of which the game objectives in each scene were aligned to the learning outcomes, and the links between the different scenes that form a particular act of the game story line, were captured.

3.1 Educational objectives, and respective methods and techniques for realisation

A brief story line for the portal "Africa as technology creator" was provided in [16]. The portal uses the concept of global warming phenomenon that causes sea water levels to raise, water to expand and the process of mountain glaciers melting to accelerate. The 20 feet rise in sea levels caused flooding, erosion and substantial loss of farmland, bio-diversity and infiltrated drinking water. At the same time, crude oil resources are almost exhausted. The quest for energy and water conservation, for wastewater minimisation, and for other natural resources for energy production is the quest for this game portal.

Here, we are going to provide some insights to the educational objectives of the portal, and the methods and techniques chosen to realise them.

3.1.1 Knowledge management

The first learning objective in the portal is to equip learners with Knowledge Management (KM) skills. Knowledge management is a critical management of processes for creating, gathering, organising, using and distributing information and knowledge. Knowledge comes in two forms - tacit and explicit. Tacit

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knowledge is personal, in people's minds, based on individual experience and involves personal perceptions, ideas and mental models. It is critical for tacit knowledge to be expressed and shared, but for this to happen it must first be turned into explicit (recorded) form, that can be easily documented, codified, transferred and shared. ICTs such as WWW offer useful environment for building a multimedia repository for explicit knowledge. In this environment information and knowledge can be captured and categorised to form a unit of knowledge, which can be disseminated to people when and where they need it. Managing knowledge in this context spans from promoting an efficient access to information from one side, to fostering innovation, from other side. This means that KM focuses on access to knowledge and expertise that create new capabilities and encourage innovation (knowledge to be transformed for use in other contexts or to create new approaches) [19].

Today, psychological models are influencing both the design and the current use of the Internet. Not only do they influence people's attitude towards the available technologies, but also provide them with conceptual grids to make sense of their interactions with technology [20]. In Montovani's model for Information foraging [20], for the first time the knowledge is referred to as a relational concept (relationships between people looking for information and the environment that they explore). The knowledge is seen as a set of complex activities (seeking relevant information, gathering it in appropriate ways, and making sense of it), as opposed to the simplistic understanding of it just as information processing. The model acknowledges the active side of the knowledge, considering it as a "strategic activity in which the critical point is that of discriminating what is relevant from what is not" [20]. But this model fails to take in consideration the social context in which the Internet experience is situated, the communication between the users. An improved version of Montovani's model appears to be the Three-level model (social context, situation, interaction) by Riva [21], which we found as an appropriate one in the realisation of the first learning objective for the portal. Surfing the Net introduces a variety of demands for optimal searching (one needs to know how to conduct a search appropriately, how to assess the relative merits of alternatives obtained, and to shared the information and knowledge acquired) [22]. In the context of the game, KM deals with an ability of players to perform meaningful, compound information search, to analyse, organise and store the information obtained and learned, to apply, share and cherish it as an important asset, and use it for effective and in-time decision-making. The very first opportunity for players to acquire KM skills comes with the necessity to perform an Internet/Intranet search about the use of coal as a raw material for liquid fuel production. The virtual cell phone is used to instantly connect learners from the VE to the real world, allowing both Internet/Intranet browsing (the game has its own browser) and voice communication. Using the game HTML editor and e-mail client, players may document the information and knowledge acquired, and may share it with the other players of the virtual environment.

3.1.2 South African technology for liquid fuel production from coal

The second learning objective aims understanding of unique local technology, which is process of complex and abstract nature. Players are presented with

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puzzle to resolve the mystery for a production of synthetic liquid fuel out of solid fossil. They have to build a model of a process system flowsheet by "assembling" (perform synthesis of) the "bits" and "pieces" of the fuel production. The "bits" are the raw material (coal), water (steam), air (oxygen), catalyst, and some intermediate and final products like crude gas, synthetic feed gas, low number hydrocarbons (C_1 - C_6), high number hydrocarbons (C_4 - C_{20}), and oil steam. The "pieces" include processes like coal gasification, gas purification, low and high temperature conversion, and refining (distillation/rectification) [16].

Models are simplified abstractions of real world events and conditions that should first be well understood before building. Because a model omits non-essential details, it is easier to manipulate it in comparison to the original entity. And this is possible because abstraction is a fundamental human capacity that permits humans to deal with complexity [23]. Models reduce complexity by separating a small number of important things to deal with at a time. Since with simulations learners are able to manipulate a model of reality and obtain immediate feedback on their actions, we decided on the educational simulation as a technique that best will help the players to achieve the second learning objective. While most of the conventional methods of instruction are aimed at preventing learners from making mistakes (or minimising the mistakes), most educational simulations are designed to give an opportunity to "learn-by-doing", in which process mistakes are not avoided, rather they form an essential part of the learning practice. With simulations learner is able to develop a better mental model and explore "what-if" scenarios, which might not be possible in the real life. Simulations situate learning in a virtual reality that is similar to the environment where learner's skills will be applied.

3.1.3 Thermal Pinch Analysis

When players finally succeed to "assemble" the system flowsheet for liquid fuel production out of coal, they will have to face the task to redesign it for better and efficient energy utilisation. Once again the explorers will have to search the Net to learn about the basic principles of Pinch Analysis, which provides a systematic approach for energy savings in industrial processes. Understanding and applying these principles for better energy utilisation and conservation is the third learning objective in the game portal.

The Thermal Pinch analysis starts with the heat and material balance for the processes. Once it is established, targets for energy savings are set prior to the design of Heat Exchanger Network (HEN) [24]. The area is well researched since mid-seventies, and many of its applications published [25, 26]. The game players have to obtain the energy targets by constructing the so-called Composite curves (a graphical representation of temperature-enthalpy profiles of heat availability and demands in the process). This will provide a counter-current picture of the heat transfer and will indicate the minimum energy target for the process. Again, through simulation techniques players will "learn-by-doing" the construction of the Composite curves and the Grant composite curve, will use the Grid Diagram to apply the Pinch Design method for retrofit of the existing HEN in order to better utilise and save energy.

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3.1.4 Wastewater treatment and combined Water-Oxygen Pinch

When the game explorers manage to redesign the process flowsheet and run the production line of the plant efficiently, they will have to take care of the problem with water contamination as a result of the plant operation. Since the story line of the game is set in global warming conditions where each drop of fresh water is precious, this emphasises the problem of environment protection, for water conservation and wastewater minimisation, along with the problem for energy conservation and minimisation. Through use of analogy techniques, players will have to learn how to apply the water and oxygen Pinch for fresh and wastewater minimisation in chemical production processes, by identifying water regeneration opportunities. And this is the last learning objective for the portal.

3.1.4.1 Water Pinch. A procedure for analysis and targeting the minimum fresh water supply uses classical Pinch concept, introduced earlier. Here, the pinch is presented by the contact point between the limiting composition curve and the water supply line. It limits the slope in contaminant concentration/mass transfer plot, and targets the minimum fresh water demand and maximum wastewater contamination. It shows the scope for water reuse, regeneration for water re-use and regeneration re-cycling prior to design. A systematic procedure guides directly the design of water flow network (treatment facility) that achieves the target [27]. The idea to implement the Pinch principles for water minimisation have led to the development of systematic procedures for Mass Exchanger Networks synthesis in 1989, generalising the concept to other mass transfer processes [28]. At present, this new life of Pinch analysis can be counted as one of the biggest successes for further extension in the application of Pinch technology.

3.1.4.2 Oxygen Pinch. The Oxygen Pinch concept is applicable to waste water treatment systems, based on biological degradation [29]. One of the most widely spread processes of such type is the activated sludge process. The idea is to target prior to design the amount of oxygen, needed by microorganisms to perform organic waste degradation and to suggest flowsheet and design changes, ensuring operation close to the earlier stated target. In most of the cases, oxygen is supplied to the microorganisms through agitation. Agitation and other means of aeration require energy, thus the analysis based on Pinch principle leads again to their original application, associated with energy conservation.

In line with such consideration, the chemical oxygen demand (COD) - the amount of oxygen required to oxidise organic carbon compounds completely to CO_2 and H_2O, is used to describe the amount of dissolved oxygen, consumed in the aerobic processes. COD is used as a universal indicator for different contamination.

The Oxygen Pinch targeting procedure sets targets in substrate growth rate, oxygen solubility, residence time (rate of substrate re-circulation), and indirectly-in oxidation energy load. The higher the slope of the substrate supply line is, the higher the specific growth rate, the smaller the residence time, the bigger the ability to handle increased substrate load (capacity), the lower the energy of oxidation, and the lower the substrate (oxygen) solubility. Thus, the procedure

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to follow is to draw the oxygen composite curve in a reversed substrate/ reversed dilution rate co-ordinate system, and lifting the substrate supply line to highest possible slope touching the composite. This graphical construction, in analogy to the other Pinch applications, guides the design of the flowsheet structure to meet the fixed targets.

3.1.4.3 Combined Water-Oxygen Pinch. The water Pinch addresses freshwater/wastewater minimisation, whereas the oxygen Pinch focuses on oxygen minimisation and corresponding energy for aeration/agitation conservation. The water Pinch deals with quantity, whereas the oxygen Pinch targets as well qualitative characteristics, such as substrate growth rate, oxygen solubility, time of residence, and oxidation energy load. Thus, the amalgamation of these two can bring the analysis to another level, where the benefits of energy, water and environment protection are combined.

Providing game players with knowledge about such powerful tool for decision making in changeable economic and technology environment can equip them with critical skills to become resourceful industrial developers and operational managers.

4 Conclusion

The presented paper targets the usefulness of the interactive learning technologies (3-D desktop virtual reality games, in particular) in creation of a unique learning environment, based on sound pedagogical theory in important areas as energy and water conservation, and wastewater minimisation. It attempts to show that such tool may be a viable instrument to intensify the process of learning about abstract and complex in nature engineering aspects by helping individuals to develop their learning, critical thinking and creative skills. Through use of story line in a particular game concept, analogies, metaphor, simulation, and avatars, learners play an active role in creation of their own collaborative virtual environment, that can be even more educational, entertaining and "real" than the real world. Evaluation of the portal (in the context of the whole project) will follow the game implementation.

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