Development of a 3D Virtual Learning Environment to Address Misconceptions in Genetics

David Baxter and Alan Amory
Centre for IT in Higher Education, University of KwaZulu-Natal, South Africa
baxterd@ukzn.ac.za; amory@ukzn.ac.za

Abstract: This paper describes the development of the genetics component of an educational adventure game, *Zadarh*, aimed at addressing learning misconceptions in biology, in the context of the appropriate application of theories of learning, and reflects on the processes used in designing the story and developing puzzles. Although there are elements of games that may reflect constructivist principles for learning, the design must be guided by a clear relationship between pedagogical principles and game design elements to deliver an engaging learning experience for the learner. The implementation of the design was guided by a number of conceptual models, namely the Game Object Model (GOM) and Game Achievement Model (GAM). Both clearly describe the relationship between learning objectives, story and puzzles, but greater guidance is suggested in guiding the design of puzzles.

Introduction

This paper discusses an approach to education using a computer-based adventure game where students can explore graphical problem-solving virtual environments that aim to challenge their misconceptions and foster understanding of complex biological concepts.

Our conception of knowledge falls within the constructivist framework with a view of knowledge that is internally depending on prior experience, mental structures and our beliefs used to interpret objects and events (Jonassen, 1991). Learning cannot occur unless an individual is in a state of cognitive conflict (disequilibrium). It is this equilibration process balancing between assimilation and accommodation that has been proposed by Piaget as the mechanism to explain learning (Fosnot, 1996). Meaningful interaction forms the core of the learning activity. Learning is encouraged in rich complex environments where learners take ownership for their learning (Savery and Duffy, 1995) where complexity and authenticity (Bednar, Cunningham, Duffy and Perry 1991; Honebein, Duffy and Fishman, 1993) are emphasised. Technology offers tools to support the realization of these environments where the appropriate pedagogy is emphasised. Many authors have lamented previous failures of the rich promises of technology. Behavioural concepts of learning dominated the early use of technology in the form of Programmed Instruction and various forms of CAL. As Reeves (1995) states, “it is a vehicle for the pedagogical dimensions we wish it to carry. It is pedagogy that ultimately determines its effectiveness and worth.”

This approach to learning and role of technology is embodied by *Zadarh* (Amory, Naicker, Vincent and Adams 1999; Amory, 2001), an adventure game designed as a learning resource to address misconceptions identified in specific biology domains students consider to be the most difficult.

Learning with Games

Rieber (1996) reviewed the benefits of play as an important learning activity and relates it to Piaget’s consideration of it as an assimilation strategy (where imitation was an accommodation strategy) proposing that games serve as a vehicle for play and imitation (Rieber, 1996) - two vital functions in the equilibrium process. Playing a game successfully may require extensive critical thinking and problem solving skills, facilitate spatial skills, social development, computer skills and literacy (Rieber, 1996; Greenfield, 1994; Betz, 1995). Computer games offer possibilities of richly detailed and engaging immersive virtual worlds (Dede, 1995, Thomas and Macredie, 1994) and support self regulated learning (Rieber, 1996).

Furthermore, Prensky (2001) argues that computer-based or digital games are essential to address the learning requirements of the modern 'digital' generation. Theoretical support for the educational use of computer games has been primarily based on the framework for intrinsically motivating instruction (Malone, 1981; Lepper and Malone, 1987). In analysing what makes games fun Malone suggests that intrinsically motivating environments provide features such as challenge, curiosity, fantasy and control. A further input into game design is the notion of immersion from virtual reality games (Quinn, 1994) and engagement, proposed by Laurel (1991), to represent the way drama captures our interest. However game designers must balance the demands of intrinsic motivation, experiential and reflective cognition as intrinsic motivation may also interfere with learning (Rieber and Noah, 1997). Norman (1993) discusses the importance of reflective cognition to learning.

Adventure games inherently afford opportunities for reflection (Quinn, 1994). According to Murray (1997) they embody a classic fairy tale narrative of danger and salvation whose appeal may be attributed to the union of a cognitive problem (finding the path) and an emotionally symbolic pattern (facing danger), and serves as an active form of the metaphor of an immersive visit where the focus is on the protagonist who must find his or her way through a series of obstacles. Furthermore, the navigation space of the computer makes it suitable for journey stories. Each move is like a plot event in a simple but compelling story, and the computer based journey stories offer a way of savouring the pleasure of uniting problem solving with the active process of navigation and exploration. Games that require players to explore and discover strategies that guide success can be construed as constructivist (Quinn, 1994).

Game Design: Designing *Zadarh* Genetics

While games provide a goal driven framework, Quinn (1997) stresses that they are not themselves educational but provide elements of a learning process. In addition, Gredler (1996) identifies a lack of well-defined research studies and need for effective design models. Pedagogical approaches to the use of games were noted by Quinn (1994) as tools for supporting drill and practise and secondly the use of games where discovery and exploration is encouraged, typically categorised as adventure games, consistent with modern theories of learning. Both Quinn (1994) and Rieber (1996) propose that the attributes of microworlds, simulations and games offer potential for guiding the design of interactive learning environments, to support structure and motivation, personal discovery, exploration and ownership of knowledge. In other words, "learning environments that encourage people to play."(Rieber, 1996).

The conceptualisation of a Game Object Model was described as a guideline for the development of educational games by providing a link between game elements and the pedagogical principles (Amory *et al*, 1999; Amory 2001). It consists of a number of components that describe the game on a number of levels from the game space component which contains the visualization space which, in turn, includes game elements and problem components. Pedagogical elements are represented by abstract interfaces and game elements by concrete interfaces. Higher level abstract pedagogical concepts thus grow out of concrete components which provide the elements for designing the learning experience. However an understanding of how design features achieve pedagogical aims is important in approaching the design. The GOM forms the basis for the Game Achievement Model (GAM) which provides a framework for the process of designing educational games. The model can be divided into 3 general phases. Firstly, the defining of learning objectives and basic story outline. Secondly, the definition of acts, act objectives and storyline interfaces. By dividing the game into acts and scenes, one can specify specific objectives for each act which must then be realized in the third phase of the model, the scenes, any number of which may comprise an act. A scene includes a number of spaces: Elements, Actors and Problems. The Elements space includes the Graphics, Sound and Technology interfaces; the Problem space contains a number of spaces (Literacy, Communication, Memory and Motor) and their associated interfaces

The general theme for *Zadarh* had already been established (Amory *et al.*, 1999). Players undertake a mission to a remote research facility where a lethal virus has been released and claimed the life of a scientist working on the antidote. The facility has been sealed and evacuated, and the player is invited to recover the antidote. Upon accepting the mission the player, wearing a biohazard suit, is transported to the facility where they must navigate a maze; collect skulls and ultimately find a vial of RNA; extinguish a fire and replenish their oxygen supply; and finally locate the hidden antidote. Through exploration the player learns more as the story is revealed through puzzles and other forms of information embedded within the environment. The game was implemented as a firstperson 'point and click' interface using pre-rendered graphics. The graphic resources were created using virtual sets created in *discreet* 3ds max® and *Adobe* Photoshop®.

The framework for approaching the game design of the Genetics component was based on the GAM (Amory, 2001), which emphasises a set of learning objectives as the foundation to guide the design process to achieve the pedagogical principles of the learning environment. The design was thus approached on two levels, namely the overall storyline and on an individual problem level within the framework of the GAM. Honebein *et al*., (1993) has emphasized a holistic view of the task complex in approaching the design of learning environments in terms of both global and local levels. While these were approached separately they were closely linked and informed the design of one another.

Defining Learning Objectives

The identification of specific learning misconceptions (Ivala, 1999) provided the basis for developing a set of learning objectives for *Zadarh*, which were supplemented by current literature on genetics misconceptions (Table 1).

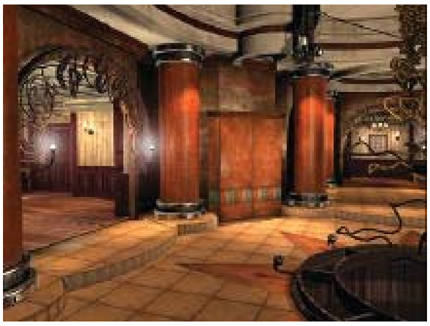
Table 1. Learning Objectives derived from misconceptions.

1. Understanding of the concept of the gene and its role in determining physical characteristics
2. Understanding of the concept of ploidy
3. The process of mitosis and its significance in the life cycle
4. The process of meiosis and its significance in the life cycle
5. The process of symbol formation and deriving patterns of inheritance

Developing a Story Structure

A constructivist approach to learning emphasizes the importance of learning in context where learning is anchored or situated in authentic environments (Brown, Collins and Duguid, 1989). A general story premise and environment was established within a museum of genetics (Figure 1) that would form part of the greater research facility where the player would be required to locate the antidote to the virus. A concept map of the concepts that were identified by the learning objectives was used to visualise the relationships between different concepts within the environment and guide the matching of potential sub-problems to learning objectives, and associated rewards. This proved important as the subject of genetics has many interrelated concepts and the resulting hierarchical puzzle structure was designed to encourage reflection. A dramatic structure was developed by arranging the placement of problems and their associated rewards to keep the player constantly engaged (Laurel, 1991) and motivated. Flowcharts were used to visualize the flow of players actions through the environment and a tentative act structure was defined and subsequently refined as the puzzles that were designed influenced the layout of the story.

Act I provided brief orientation and exposition where the player discovers an abandoned facility where they are free to explore numerous displays and the professor's study. Act II introduced conflict as the player accesses the professor's laboratory and while taking steps to find the antidote makes discoveries that what they have been told by the company who hired them is not all what it seems. Through the exploration of the concepts outlined in the learning objectives, the player learns more about the antidote and where to access it. Information of genetics and moral issues are also introduced. Successfully locating the antidote would involve finding information about antidote which takes the form of an edible vaccine and where it was hidden which ultimately via controlled access. Act III involves the player obtaining the antidote and faced with a decision on what to do with it as they seek to resolve the conflict.



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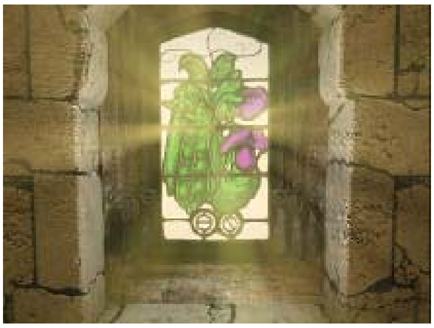

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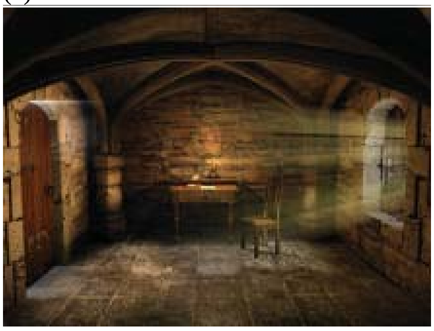

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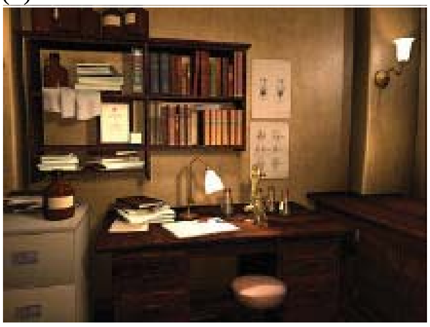

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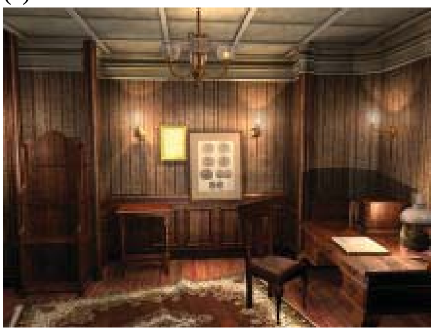

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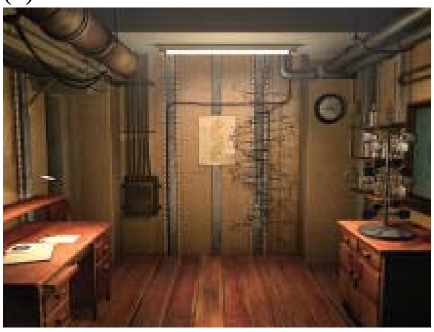

(f)

Figure 1(a) Genetics Museum interior. (b) Stained glass window. The learner uses this to derive symbols to achieve solve a puzzle related to the gene concept. (c) Mendel display. (d) "Fly Room" display. (e) Meiosis display and (f) DNA display.

Designing Puzzles

Careful design of problems is required to achieve pedagogical aims and fulfil promises of games for learning. Problems are central to constructivist learning environments (Jonassen, 1998). Tasks, or problems, form part of a larger environment or task complex, which captures a larger context in which the problem is relevant (Bednar *et al*., 1991; Honebein *et al.*, 1993; Savery and Duffy, 1995). Using Laurel's (1991) concept of designing the action as basis for approaching the design i.e designing interesting activities that engage, the whole activity was designed as something able to provide satisfaction and sufficient reward on completion. A hierarchical approach to the layout of problems was implemented to promote challenge (Malone and Lepper, 1987). The development of one of the puzzles (dealing with the concept of ploidy), its relationship to the story context and resource definition is discussed.

Conceptual development of puzzle: definition of parameters & objectives

Several authors note the existence of at least one form of the ploidy/ chromosome structure misconception (Brown 1990, Smith 1991; Stewart, Hafner and Dale 1990; Ivala, 1999). This is due to failure to show origin and relate replication to origin of the two chromatid chromosomal structure. Suggestions for instruction include clearly defining origin of the replicated chromosome structure and distinguishing between chromosome structure and number (Kindfield, 1991); and present changes in chromosome structure and ploidy and cell division processes in context of lifecycle and cell cycle (Smith, 1991; Kindfield, 1991). These misconceptions provided a foundation for developing an approach to addressing the ploidy misconception which is stated as: students believe chromosome structure dictates ploidy (replicated = 2n; unreplicated = n; chromosomes exist only as replicated structures; chromosomes exist only as unreplicated structures).

The approach to the design and specification of the puzzle, derived from the stated learning objectives, is outlined in Table 2.

Table 2. Ploidy puzzle specifications

Statement of student misconception/ current state of knowledge & understanding
Chromosome structure dictates ploidy (replicated = 2n, unreplicated = n);
Chromosomes only exist as replicated structures;
Chromosomes only exist as unreplicated structures

Definition of terms
Chromosomes structure change is due to cell cycle phase
Ploidy is defined as the number of sets of chromosomes within a cell or organism. Each set is designated n so one set is n is haploid, two sets is 2n is diploid. Ploidy (diploid/ haploid) is a function of the number of sets of chromosomes present.

Demonstrating understanding
Change ploidy by change number of sets
Change chromosome structure by cell cycle.

Define resources required by player
Inheritance theories (blending v particulate). A set of chromosomes is inherited from each of our parents.
Cell cycle and changing chromosome structure.
Ploidy changes a result of meiosis.

Posner, Strike, Hewson and Gertzog (1982) hypothesise that four conditions have to be met before learners change their existing mental models, namely: dissatisfaction with existing ideas, understanding of coherent new ideas, plausibility of the new idea and fruitfulness of the new idea in being useful. The student is this required to actively reshape their existing concepts (Dreyfus *et al*. 1990). Principles derived from alternative conceptions and cognitive conflict research (Nussbaum and Novick, 1982) informed the design process. Firstly, the incompleteness of understanding was highlighted: naïve concepts don't 'function' in environment. In order to achieve their goal the player is able to change either the structure of the chromosome or the number of chromosomes. The idea is that changing chromosome structure will have no impact on the resulting ploidy, in conflict with naïve understanding. In terms of Malone's (1981) identification of intrinsically motivating principles, this aims to promote cognitive curiosity; surprise and intrigue player by paradoxes and incompleteness of the their knowledge in relation to the environment. The story context provides interest as well as motivation to solve the problem as the player seeks to discover more in the game. Secondly, in order to promote meaningfulness (as player does not always reach conflict state), the problem must challenge the player: the goal oriented nature of game context contributes to providing meaning and highlights the need for clear goals. In addition, the story context may drive the search for meaningfulness (narrative fantasy) as is the importance of performance feedback which must be supportive and constructive. The new concept is useful in that it enables the player to proceed within the environment. Finally, the role of self-esteem for learners is important as the problem should not appear threatening but serve to challenge the player. Furthermore sufficient resources are provided to support the player in solving the problem.

Resources to scaffold the learner in solving the problem were defined with an emphasis to encourage the derivation of principles and relationships. These resources were then assigned scenes within the environment. Similarly, there were other supporting resources embedded within the environment which were already defined. These include detailed interactions to discover the relationship of chromosome structure to cell cycle and the origin of the replicated chromosome structure, and the role of meiosis and fertilization as affecting ploidy. These were specified and guided the development of the environment whereby additional scenes were added to the original conception.

Visual puzzle design – creating the elements

Generally, problems in adventure games concern access to a i) new location ii) new object or iii) new information The goal of the "Ploidy Puzzle" was to gain access to a new location and ultimately new information contained in the Professor's laboratory. Conceptually, the puzzle is essentially of a code and panel variety. However the visual design attempted to add interest by weaving the i) story context (i.e. a museum with displays) and ii) contextualize the knowledge content into the design to aspire to develop what Quinn (1997) might be referring to when he describes a 'coherent theme'. Hence the concepts being dealt with are reflected in the design, and similar designs are employed for other objects within the game that may relate to this particular puzzle.

The visual design was approached by creating the 'panel' of the problem as part of one of the museum displays. It is thus interesting in forming part of the story environment and maintains the motivational fantasy. In addition the display forms part of a group of sculptures on inheritance, each related to a different aspect. The 'code' to access the door was the result of specifying the correct ploidy associated with the desired result required by the player. The player interacts with the statue/ display to learn about what is required of them to solve it and develop a set of rules that might guide success. The problem serves not as an example but where the player discovers the rules. The emphasis is on the quality of the interaction – of the player 'at play' discovering the rules for themselves. This leads to the importance of feedback. The feedback, along with supporting information is intended to scaffold the player.

It is debatable whether the "Ploidy Puzzle" can strictly be classified as an authentic task. It does retain elements thereof and the emphasis is placed on Jonassen's (1998) definition where meaningfulness is ascribed to the learner. Learning of content is embedded in the use of that content (Bednar *et al*., 1991) and the task is embedded in a motivating environment, which the player may find meaningful and while the use of the knowledge in the environment may not be strictly authentic, its context within the knowledge domain.is emphasised. The environmental context is critical – information is not independent abstract entities but context forms a link with knowledge embedded within it (Bednar *et al*., 1991).

Conclusion: Refining a process for design

The game is currently under development and this paper reflects lessons learnt from that process. While the GAM emphasised the importance of learning objectives and provided a good organisation of the structural composition of the game in terms of acts, scenes and problems, the process of designing puzzles may require additional guidance. As an example the design of the Ploidy Puzzle illustrates the use of a detailed definition of terms related to the misconception and applied the use of cognitive conflict to guide the design. The problem is the core of the constructivist learning environment and it is important to design activities that are both educational and fun.

In addition the iterative nature of the design process is emphasised. The design of the game was approached on two levels, namely the story and problems. The design of the story included integration of problems and their relationship to one another within the context of the story environment. The design of problems focused on the quality of the interaction between player and environment and how learning objective might be achieved as well as specifying what resources might be required to support the player in solving the problems which could then integrated into the environment.

Moreover, it is important to design locations that include puzzle based objects that appear to have a function or context within the game world. The emphasis here is on the building meaning into the design as puzzles are most satisfying when they have dramatic appropriateness, and serve as a way of increasing our belief in the virtual world (Murray, 1997). This relates to motivational aspects of player control (even if only an illusion) and building an endogenous fantasy that is immersive and does not fall apart when conspicuous objects appear in environments for no apparent reason other than to provide an obstacle. This is not always possible but should be aspired to facilitate an engaging experience.

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