ADDRESSING GENETICS MISCONCEPTIONS WITH AN EDUCATIONAL GAME

by

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Submitted in fulfillment of the academic
requirements for the degree of
Master of Science in the
School of Life &
Environmental Sciences
University of KwaZulu-Natal
Durban

August 2008

PREFACE

I, David Gordon Baxter, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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August 2008

ACKNOWLEDGEMENTS

I have benefited from the support of many friends, colleagues as well as family.

My supervisor, Professor Alan Amory. Thank you for this unique opportunity to draw on my diverse interests. Your guidance and insight always challenged and inspired both my work and me as an individual.

There have been many colleagues who have in their unique way added so much: from Kevin Naicker and Jacky Bellengere at Bioped to Rob Seagram, Paul Rodda, Thato Foko, Reishin Toolsi, Steven Yates and Devan Govender at VLS/ITEd. No one works in isolation and especially with you lot, something of all of you has rubbed off and contributed to this. Thanks for many great memories. To my 'supporting cast' of Philip Tembu, Ben Turner, Peninah Thumbi and Ashika Deonorain: thank you for your voice work and musical talent.

I would like to acknowledge the support from the National Research Foundation which has, in addition to this research, has made it possible for me to attend and present at the following conferences: SAARDHE 2004 (Durban), EDMEDIA 2004 (Lugano, Switzerland) and EDMEDIA 2006 (Orlando, USA).

Mom and Dad. Thank you for your continuous love and support. This would not have been possible especially without your help during the last few weeks of writing up.

My dear Cheryl. Thank you always for your love and patience as I laboured over this. Now for new challenges together with the girls.

ABSTRACT

This dissertation describes the design, development and formative evaluation of an educational adventure game entitled *Food for Thought* to address student misconceptions in genetics within the context of a development research paradigm, and reflects on the lessons learnt during the process. The current investigation was a response to an assessment of learning misconceptions in genetics. Several factors were identified as contributing to these problems with a focus on the abstract nature of the subject and the decontextualised manner in which students encounter these concepts. The tenacity of the problem suggested the need for of a novel intervention.

A constructivist concept of learning emphasises active learners internally constructing their own meaning in rich complex environments. While not a theory of teaching, it offers a number of principles to guide the design of learning environments. Elements from computer based adventure games embody aspects of these principles and offer possibilities of developing a tool to address student misconceptions. Here, learners may explore biological concepts as they engage in contextual problems embedded in the narrative structure of a detailed and immersive virtual world. The implementation of the design was guided by a number of conceptual models, namely the Game Object Model (GOM) and Game Achievement Model (GAM) which clarify the relationship between pedagogical principles and game design elements. The identification of specific learning misconceptions provided the basis for developing a set of learning objectives for the game which were used as a foundation for the design of the environment, which was then created using a combination of commercial and proprietary 3D graphic and image editing software. Both the GAM and GOM are effective tools for categorizing a variety of different components in a very complex development. A formative evaluation of the game was undertaken probing both expert and user (student) responses through post-gameplay questionnaires and interviews. The game was favourably received, with feedback and suggestions on improvements. Most notable was the need for greater guidance in the game environment. In addition Activity theory was employed as framework of analysis. Activity systems for both players and the designer were developed and contradictions within and between them analysed. These were used to modify the original designer activity system and in so doing refine the practice of game design in the context of the development research paradigm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background to research

Our modern society presents a number of challenges. Developments in science and the exponential growth of telecommunications networks are contributing to a society based on human knowledge and skills for solving problems (Kurshan, 1991). However, technological advances are such that we are exposed to more information, e.g. the internet (Dede, 1992), which demands more than information retrieval skills but requires that people are able to think critically and consider the evidence before them. Critical thinking is of crucial importance as multiple media compete for our collective attention. Technological advances are not limited to media but have an impact on most aspects of our lives. There is also a need for greater scientific literacy (Cheek, 1992). In the realm of genetics these advances have immediate implications, not just for those working in the field, but to members of the public who have a role to play in how our futures are shaped by these new tools. Can professionals and public come to shared understanding on these issues in an environment of informed?

Currently genetics is considered to be one of the most difficult subjects for students in both schools and higher learning institutions. Genetics difficulties appear to be a function of both the teaching methods and nature of the subject itself. The use of technology in education offers novel solutions to effectively teach higher order thinking skills if used appropriately. While the details of curriculum change are beyond the scope of this study, technology may also serve as a vehicle for change from current didactic models. Considering the growing importance of genetics and its ever widening influence within our lives we need to ensure that not only professionals but also the general public have at least a reasonable understanding of its concepts.

There are well documented difficulties that students have with learning genetics concepts. Several studies have attempted to identify the source of student's learning problems and misconceptions, and how they might be resolved (Bahar, Johnstone and Hansell, 1999; Barrass, 1984; Cho, Kahle and Nordland, 1985; Longden, 1982; Kindfield, 1991; Stewart, Hafner and Dale, 1990). Sources of problems include: teaching methods (Banet and Ayuso, 2000), nature of the subject -- abstract versus complex (Knippels, Warlo and Boersma, 2005), terminology (Banet and Ayuso, 2000; Lewis, Leach and Wood-Robinson, 2000b), affective issues (invoke fear in students) (Pashley, 1994), and textbooks (Cho *et al.*, 1985). Although some authors feel awareness of the problem is sufficient (Pashley, 1994), others are of the opinion this is not enough. Rather, there is a requirement for interventions to facilitate student understanding of specific types of knowledge and address learning difficulties and that even alternate forms of education are required (Gil-Perez and Carrascosa, 1990; Kindfield, 1994; Nussbaum and Novick, 1982).

The use of technology and more specifically computer video games offer opportunities to address these learning difficulties within a limited learning theory paradigm. Technology has the potential to support rich learning environments advocated by contemporary theories of learning (Dede, 1992; Jenkins, 2005; Malliet and de Meyer, 2005). In addition the field of game research is growing (Amory, 2001; Barab, Thomas, Dodge, Carteaux and Tuzun, 2005; Kafai, 1994; Rieber, 2001; Rieber, Smith and Noah, 1998; Squire and Barab, 2004). Game models have been proposed by Amory (2001) and Amory and Seagram (2003) and yet there is no clear consensus over what they bring to game literature and learning. Instead these models require clarification, development and evaluation.

1.2 Methodology

The research was carried out within a developmental (design) research framework where learning problems are solved while at the same time deriving a set of design principles (van den Akker, 2000) within a mixed methods pragmatic approach. Considering the dubious reputation of educational research and the failure of traditional approaches, developmental research may serve to effectively unite theory and practice.

1.3 Overview of Dissertation

This dissertation is an extension of the investigation by Ivala (1999) into genetics learning misconceptions of first year students at the University of KwaZulu-Natal to incorporate the potential learning benefits of computer games. While this study draws together information and debate from a number of fields. It is not the intention to provide complete coverage of these fields but rather provide a broad context for a critique of the relevant literature and the significance of the problem in a topic which is considerably multidisciplinary. The structure of the dissertation is as follows:

Chapter 2 reviews theories of learning to provide a foundation for a discussion of the relationship between learning theory and educational technology. In addition the problem of student misconceptions in genetics is introduced. Genetics as a subject is regarded by both students and lecturers as very difficult. The chapter reviews current research in the field drawing together common elements that may be the causes, as well as reviews and refines proposed solutions in the literature. Finally the educational potential of games is introduced.

Chapter 3 describes the initial design and development phase of the game. The elements which are used to craft the game are discussed in detail and how they might serve as educational tools. The designers were involved in activities based on their understanding of literature and guided by game design models, i.e. the GOM and GAM. The chapter concludes with a reflection on the process and lessons learnt.

Chapter 4 discusses the formative evaluation of the initial design phase using quantitative and qualitative approaches with both expert and user reviews. Attitudes towards the game are discussed and analysed here.

Finally, Chapter 5 summarises the main features of the study and provides a discussion platform for key elements of the project arising from the initial design and development phase to the formative evaluation.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Considering the growing importance of genetics and its ever widening influence within our lives it would appear necessary to ensure an understanding of its concepts, not only for professionals but also by the general public. Learning genetics, however, is characterised by a number of learning difficulties and misconceptions. This chapter will discuss the following: 1) introduce how we learn noting paradigm shifts and constructivism as theory of learning; and how this forms the foundation for the design of learning environments establish key characteristics of learning environments based on learning theory; 2) introduce the difficulties associated with learning genetics and finally 3) discuss the suitability of computer games for learning. In addition, narrative is explored in detail as the discussion moves to a conceptualisation of games.

The current research investigation draws on a number of diverse topics and seeks to provide a synthesis thereof. It is not the intention of this literature review to cover each in detail but rather provide context for the investigation.

2.2 Constructivism as a theory of learning

2.2.1 Paradigm shifts in learning theory

The history of learning theory is characterised by a number of paradigm shifts. Land and Jonassen (2000) document the shift in contemporary learning theory from behaviourism to cognitivism and finally constructivism, with the research emphasis moving from the external environment to the individual learner (Cooper, 1993), from objectivism to constructivism (Jonassen, 1991) or more recently individual to a social emphasis (Duit and Treagust, 2003). Most theorists take positions that fall somewhere on the continuum.

Behavioural psychologists initially considered learning to be external to the learner and equated with directly observable changes in their behaviour. The mind was thus deemed to be irrelevant to an understanding of how we learn where learners who were seen as passive and in need of external motivation (Skinner, 1953, 1968). In moving to a focus on the mind and individual, constructivism has since emerged as the dominant paradigm on how we learn: education’s ‘grand unifying theory’ according to Matthews (2000) which, Duffy and Cunningham (1996) describe as currently enjoying a state of hegemony in education, although it continues to be a source of debate and controversy. What is clear is that constructivism’s influence exerts a wide influence extending to cognition, learning, teaching, education, science and personal knowledge (Matthews, 2000). Furthermore, the multifaceted (Phillips, 1995) nature of constructivism comprises an array of descriptors which include radical (von Glasersfeld, 1989), personal (Piaget, 1972), social-cultural (Vygotsky, 1978) and socio-historical (Lave and Wenger, 2000).

A reflection of this multifaceted nature is the debate between individual and social (sociohistorical) perspectives. The latter (Brown, Collins and Duguid, 1989; Cole, 1992; Rogoff and Lave, 1992) emphasise the characteristics of social participation, relationships, setting of activity and historical change; whereas the former (Cobb, 1994; Piaget, 1972; Tobin and Tippins, 1993; von Glasersfeld, 1989), emphasises how knowledge is constructed as a result of the learner's action and interaction in the world. This debate is, however, not considered divisive. Many consider the approaches to be complementary rather than irreconcilable (Cobb, 1994; Duffy and Jonassen, 1991; Greeno and Moore, 1993). According to Fosnot (1996):

> "The important question to be asked is not whether the cognizing individual or the culture should be given priority in an analysis of learning, but what the interplay between them is .... We cannot understand an individual's cognitive structure without observing it interacting in context, within a culture." (p. 23)

In terms of considering the many different views of learning, (Duit and Treagust, 1998) extend the call for an inclusive approach to different conceptions of learning. They note:

> "With regards to the different views of learning, we believe that rival positions emphasise different aspects of the learning process. Further research should not focus on the differences but present an inclusive view of learning and conceptualise the different positions as complementary features that allow researchers to address the complex process of learning more adequately than from a single position." (p. 3)

Rather that focusing on differences, researchers are taking a multi-dimensional approach to constructivism and learning where different perspectives may provide different and unique insights. Having discussed the variety of faces of constructivism, the key ideas will now be addressed.

2.2.2 Knowledge construction

Learning according to constructivists has commonly been described as the active construction of knowledge in a meaningful authentic context (Duffy and Cunningham, 1996). According to von Glasersfeld (1996), the key idea setting constructivism apart from other theories of cognition was Piaget's idea that knowledge is not produced as a representation of an independent reality, but rather as an adaptive function.

> "Knowledge cannot be conceived as predetermined either in the internal structures of the subject – they are due to an effective and continuous construction; or in the pre-existing characteristics of objects, since they are only known through mediation of these structures …" Paiget (1972 p. 14)

Piaget (1972) goes on to add:

> "knowledge is not an objective entity. Instead it is the interaction between the individual and the environment…."

Our prior knowledge about the world is therefore important and influences the way we learn. This is reflected in Jonassen (1991, p. 10) where he writes

> "we thus conceive of an external reality based on our unique set of experiences with the world and our beliefs about them where knowledge is internally constructed depending on prior experience, mental structures and our beliefs used to interpret objects and events."

This, however, does not preclude the existence of a real world as many assume, i.e., a form of relativism. Constructivism is not a denial of reality but what we know about it is subjective (Tobin and Tippins, 1993) where meaning is imposed on the world by us, rather than existing in the world independently of us (Duffy and Jonassen, 1991; Tobin and Tippins, 1993).

The processes for learning were described by Piaget as assimilation and accommodation (Piaget, 1972). Assimilation is the process of an individual adapting new ideas into existing structures while accommodation involves the restructuring of existing cognitive structures when new information does not conform with existing structures. Conceptual conflict arises when new ideas do not fit with existing structures. The balance is restored through the process of equilibration, which is an interplay of assimilation and accommodation.

While constructivism draws on Piaget's conception of the nature of knowledge, Vygotsky (1978) moved the focus to human culture and the use of signs and symbols in higher cognitive function. The next section explores this social perspective on learning within the constructivist paradigm.

2.2.3 Towards a social conception of learning

A historical approach was used by Vygotsky (1978) to analyse the development of higher cognitive processes in the context of human cultural history. Through the process of signification, humans have developed a variety of signs and symbols to enhance the cognitive abilities of each new generation and in doing so, move beyond their biological function (Gredler, 1992). Vygotsky (1978) introduced the zone of proximal development which represents the difference between the actual development level of an individual as determined by independent problem solving, and a level of potential development as determined by collaboration with peers. Indeed, a central feature of learning is that it creates a zone of proximal development. As noted by Wertsch, Minick and Arns (1984), Vygotsky’s position does not exclude the importance of individual experience but rather serves to emphasise the centrality of social factors.

Activity theory is becoming an increasingly popular research tool for analysing human activity (Roth and Lee, 2007). It is a framework for describing activity linking individual and social levels (Engeström 1999) - a "theoretical and methodological lens for characterizing, analysing and designing for the participatory unit" (Barab, Evans and Baek 2004). According to Jonassen and Rohrer-Murphy (1999) activity theory provides an appropriate framework for designing constructivist learning environments. Its appropriateness is derived from its focus on the interaction of human activity and consciousness within a relevant context. Its origins are in classical German philosophy, Marx and Engels, and in the Soviet Russian cultural-historical psychology of Vygotsky, Leont`ev and Luria but has now emerged with international popularity (Engeström 1999). Vygotsky (1978) maintained that all psychological activity is mediated by a tool or instrument. His original concept subject, object and tool was modified by Engeström (1999) to incorporate the social mediations of Leont`ev (1978), i.e. rules, division of labour and community.

> “Activity cannot be understood or analyzed outside the context in which it occurs. So when analysing human activity, we must examine not just the kinds of activities that people engage in but also who is engaging in that activity, what their goals and intentions are, what objects or products results from that activity, the rules and norms that circumscribe that activity, and the larger community in which the activity occurs.” (Jonassen and Rohrer-Murphy, 1999 p. 62)

The components of any activity are organised into activity systems. The activity consists of a hierarchy of actions, namely operations, actions and activities (Leont’ev, 1978).

In summary, constructivism emphasises the personal constructed nature of knowledge with a focus on prior learning, accommodation, assimilation and equilibration in learning. In addition to a focus on the individual there is movement towards a social conception of learning. Both offer different perspectives and should be considered as complimentary views on learning.

2.3 Educational Technology & designing learning environments

2.3.1 A separation of theory and practice

The field of educational technology has promised much but generally not lived up to expectation. A key reason for this has been a focus on technology (Clark, 1991, 1994; Cuban, 2001; Reeves and Hedberg, 2003) rather than a grounding in learning theory. Indeed, it has been argued that emerging technologies require a framework for adoption that is based on appropriate theory (Greening, 1998). Additionally, interactive multimedia environments may appear desirable to students based on 'trimmings' rather than the learning benefits and, according to Atkins (1993) may be more likely to include elements of bad pedagogical design. To appreciate the reasons for this, it is necessary to consider the context from which educational technology began.

Both educational technology and instructional design emerged at a time when behaviourism was the prevailing paradigm for studying learning. Within this framework grew the initial instructional design methodology (Gagne, Briggs and Wager, 1988; Gagne and Dick, 1983). Despite the paradigm shift in learning theory towards the cognitive sciences, instructional design remained entrenched within the behaviourist framework. Winn (2002) has drawn attention to this separation of theory from practice in his discussion of the history of educational technology. Although behaviourism has shouldered much responsibility for what is wrong with education, Wilson and Myers (2000) do not consider this criticism to be fair. With the growth of the constructivist influence, instructional design perhaps required a new paradigm but the reaction to the constructivist influence has been mixed (Lebow, 1993; Merrill, 1991). It is only with the increased attention given to development research (Reeves, 2000) that theory and practice have the potential to inform one another once more and so build relevant and effective educational solutions. In the next section constructivist implications for the design of learning environments grounded in learning theory will be discussed.

2.3.2 Towards design principles

Numerous authors have discussed constructivist implications for the design of learning including Koschmann, Myers, Feltovich and Barrows (1994), Lebow (1993) and Savery and Duffy (1995) and comprising a variety of assumptions, principles and values. These many principles are most effectively summarised as: anchor all learning activities to a larger problem; support the learner in gaining ownership of the overall problem; authentic tasks; encourage learner ownership of the problem solving process; support and challenge learner's thinking; encourage testing ideas against alternate views (social negotiation); and provide opportunity for reflection on both content and process (Savery and Duffy, 1995). Despite this, the elements required for constructivist learning often fail to provide adequate guidance (Oliver and Herrington, 2003) possibly due to the intensive focus on theory which results in oversimplification and context dependency. Indeed constructivism is commonly considered a 'means of thinking about design rather than a vehicle for the process of design’ (Wilson, 1995).

The design of constructivist learning environments has emphasised the centrality of learning tasks. Oliver and Herrington (2003) describe the design of learning environments based on pedagogy in terms of learning tasks, resources and supports. They argue for a design approach that focuses on appropriate learning tasks as central rather than just as practice, where “activities function as the organizing feature for learning”. The content therefore acts as a support rather than the focus of the environment. Examples of learning designs that use this approach are situated learning (Cognition and Technology Group at Vanderbilt, 1992), problem based learning (Barrows, 1986; Savery and Duffy, 1995) and anchored instruction (Bransford, Sherwood and Hasselbring, 1988).

Activities that have been described to best support this are authentic tasks where the context reflects the way knowledge is used in real life, and tied to situations in which they are learned (Brown *et al.*, 1989). Grabinger (1996) suggests the teaching of skills in context of their use. Context is therefore considered to be integral to meaning: abstracting or simplifying concepts strip their meaning (Bednar, Duffy and Perry, 1992) resulting in inert knowledge (Cognition and Technology Group at Vanderbilt, 1993). Furthermore context facilitates knowledge links between internal and external aspects of a knowledge domain (Brown *et al.*, 1989).

Oliver and Herrington (2003) highlight the need to plan learning settings based on meaningful and relevant activities and tasks. What exactly does authentic imply? Bednar *et al.* (1992) represent the pragmatic approach in considering the opinion of the learner as a task’s apparent authenticity. Herrington and Oliver (2000) characterise authentic design features as authentic contexts and activities including collaboration and reflection. Learning in context facilitates the development of usable knowledge. Abstracting concepts from their theoretical position strips their meaning (Bednar *et al.*, 1992). Authenticity encourages ownership (Oliver and Herrington, 2003) which is critical for active student engagement.

To summarise, learning theory is key to developing effective digital learning tools constructivism offers a set of guidelines to guide the design process where there is an emphasis on authenticity and context.

2.4 Perspectives on Learning and Understanding Genetics

Genetics is considered to be one of the most difficult subjects encountered by teachers and students (Bahar *et al.*, 1999; Johnstone and Mahmoud, 1980; Lazarowitz and Penso, 1992). Considering the growing importance of genetics and its influence in our personal, social and political lives, there is a need to improve understanding not only for professionals but also the public - a need for better 'genetic literacy' (Knippels *et al.*, 2005). From a survey of students in their final year of schooling which showed a lack of basic knowledge about the structures involved in the transfer of genetic information Lewis and Wood-Robinson (2000) stressed that considering the rapid advances in gene technology, this limited and confused understanding is a cause for concern. From these results, the authors concluded that the current approach to science education appears to be an inadequate preparation for students either as future scientists or in interactions with science in their personal lives. (Wood-Robinson, Lewis and Leach, 2000) distinguish between inheritance and genetics (which includes the mechanism thereof), suggesting that perhaps too much focus has been placed on inheritance. More recently, there has been shift in the focus of research from patterns of inheritance to understanding of structures, processes and mechanisms has been noted by Lewis and Kattmann, (2004). The details of student understanding of genetics concepts will now be explored in the following section.

2.4.1 Identifying misconceptions and learning difficulties

Several investigations have revealed a lack of understanding of most genetics concepts. Not only do students lack understanding but also show evidence of a number of misconceptions related to genetics concepts. Generally, the more common learning difficulties and misconceptions include a limited understanding of the structures associated with genetics and their associated functions (Lewis, Leach and Wood-Robinson, 2000a; Lewis and Wood-Robinson, 2000). These may be loosely organised around:

i) *Structures of genetics, i.e. chromosomes, genes and alleles*: relationships between: genes, chromosomes and alleles (Banet and Ayuso, 2000; Lewis and Kattmann, 2004); dominant and recessive alleles (Heim, 1991); allelic pairs and trait expression (Radford and Bird-Stewart, 1982); chromosomal separation and DNA replication (Longden, 1982).

ii) *Processes of genetics, i.e. cell division*: the events, significance and differences between mitosis and meiosis (Lewis *et al.*, 2000b), including alternate views of meiosis (Banet and Ayuso, 2000); the nature of transfer of genetic information (Wood-Robinson *et al.*, 2000); the relationship between chromosomal movement and trait transmission (Tolman, 1982) as well as meiosis and chromosome number (Kindfield, 1991).

There is also often a general confusion over terminology (Lewis *et al.*, 2000b; Banet and Ayuso, 2000) and mathematical and analytical aspects. In many of these examples, problems involve understanding the relationships between concepts. In the next section the reasons for this is explored further.

2.4.2 The abstract nature of genetics

Why is genetics considered to be so difficult? Several studies have attempted to identify the source of student's misconceptions, and how might they be resolved (Bahar *et al.*, 1999; Barrass, 1984; Cho *et al.*, 1985; Longden, 1982; Kindfield, 1991; Stewart *et al.*, 1990). Sources of misconceptions include: teaching methods (Banet and Ayuso, 2000) the complex abstract nature of the subject (Knippels *et al.*, 2005) - multiple levels of thought and scale, terminology (Lewis *et al.*, 2000b; Banet and Ayuso, 2000), affective issues – students are afraid and intimidated by the subject (Pashley, 1994), and the approach to information presentation in textbooks (Cho *et al.*, 1985).

One of the main sources of these difficulties is the very nature of the concepts dealt with in genetics: the concepts are generally considered to be abstract. The subject matter comprises a complex domain ranging scale and time, and concepts of chromosomes and genes of which students often have limited prior experience. Bahar *et al.* (1999) identifies the ideas and concepts of genetics as existing on three different levels of thought (macro, micro and representational) contributing to difficulties in understanding the concepts. Students are required to engage in multiple levels of thinking as they encounter concepts at different levels of organization - macro (organism) to micro (DNA, cells) to symbolic (genotype) (Bahar *et al.*, 1999; Johnstone and Mahmoud, 1980). What makes learning about sub-cellular processes problematic for students is that one has virtually no experience with them (Kindfield, 1991) and many of the concepts, particularly at the molecular level, are abstract (Malacinski and Zell, 1996). For Bliss (1995), the learning of concepts is an issue of accessibility. The abstract nature renders concepts inaccessible and thus difficult to learn and a source of misconceptions.

When there is no opportunity for experience (Lawson, Alkhoury, Benford, Clark and Falconer, 2000), direct observation and representation plays a crucial role. Representation however introduces a number of problems: oversimplification, too much detail, representation of the temporal nature and scale of structures, wide interpretation by users, no labels, novices and experts differ (Buckley, 2000). Misconceptions at the macro level arise from contradictions with everyday experience (Halldén, 1999). At the micro level, a player's experience is limited to their presentation in textbooks as isolated representations of structures and processes, particularly inanimate stage diagrams (Longden, 1982; Radford and Bird-Stewart, 1982). To illustrate the resulting implications of representing concepts and structures in a particular way, an example of chromosomes is given below:

> "Probably the single most confusing image in teaching and learning genetics is the practice of representing chromosomes (generally autosomes) as their mitotic metaphase X-like appearance. If students could grasp that these are mitotic metaphase conformations, then all would be well. Unfortunately, this X representation of chromosomes is often learned early on, in high school or in previous courses, and is so universally accepted that students automatically assume that this "X" is the normal appearance of all chromosomes regardless of their stage in the cell cycle." (Griffiths and Mayer-Smith, 2000 p. 52)

The replicated metaphase chromosome has thus come to represent the standard appearance of chromosomes with consequences for understanding genetics processes. Furthermore, students have few opportunities or support for linking concepts. An understanding of genetics depends on a number of interrelated concepts that contribute to the understanding of one another.

Complex concepts require basic ideas to build on, i.e., a gene is a length of DNA which codes for a particular product, a gene has a specific location on a chromosome, genetic code universal for all organisms (Lewis *et al.*, 2000a). Focusing on the physical link between genes and chromosomes is suggested as a base for a clearer understanding of related processes (Lewis *et al.*, 2000b). Similarly, DNA replication and its method of teaching is considered by many as key to the understanding of many related concepts such as mitosis, meiosis and fertilization, inheritance and terminology (Cho *et al.*, 1985). The relationship between meiosis and inheritance is however rarely linked (Allchin, 2000; Halldén, 1999). While it is also important that students comprehend why links are important and seek them for themselves, they often fail to connect concepts in genetics (Venville and Treagust, 1998).

Considering the difficulties associated with genetics the next section discusses a novel approach to learning and potential solution to the challenges afforded by learning genetics.

2.5 Learning With Computer Games

Any intervention to address student understanding must support student access to the concepts of genetics, where they can interact with and form links between, in an engaging and supportive environment. Constructivist learning demands learners that are actively engaged, although the question is how does one engage learners? A popular method is through the use of interactive computer games which offer novel ways of supporting learning in complex learning environments and overcoming the challenges of learning biological concepts. The use of interactive multimedia enables new ways of overcoming some of the challenges of representing biological phenomena (Tsui and Treagust, 2004). It allows the inclusion and integration of different kinds of representations linked and structured in many ways, presumably supporting learners with diverse aptitudes and preferences for particular representational modes (Buckley, 2000). Thus games combining the representational capabilities of the computer with the structure of problem based activities in a meaningful context may provide opportunities for learners to interact with and experience previously inaccessible concepts with opportunities to form links between them. This potential for learning is discussed in the following section.

2.5.1 Suitability Of Games For Learning

The engaging nature of computer games has been the source of resurgent interest particularly in their potential to support constructivist learning principles in complex and sophisticated learning environments including that of learning genetics: active learners, representation and visualisation. Previous explorations of the suitability of games for learning have focused on Malone's framework of intrinsic motivation describing what makes games fun (Malone, 1981a, b; Malone and Lepper, 1987). Learning that is fun appears to be more effective (Cordova and Lepper, 1996) and the elements of fantasy, curiosity, challenge and control (Lepper and Malone, 1987) all contribute to the fun in games (Malone, 1981a, b). 'Fun', however, does not imply 'easy'. There is common association of games with making learning 'easy'. This approach is characteristic of much of the edutainment genre. Criticism of this focus on learning as easy comes from Papert (1998) where he writes:

> "there is a preoccupation with 'making it easy' and an ineffective and immoral attempt to 'hide' learning under the guise of making learning fun." (p. 88)

The emphasis on learning in games as 'easy' leads to false student expectations (Buckingham and Scanlon, 2000) with games that in reality are neither fun nor include play (Fortugno and Zimmerman, 2005). Rather than a focus on making learning easy, Papert (1998) suggests the application of hard fun, that learning should not be easy and what makes games fun is the very nature of them being hard i.e. engagement in challenging activities. Other authors refer to serious play (Rieber *et al.*, 1998).

Approaches to concept learning currently focus on incorporating both cognitive and motivational goals in developing learning solutions (Pintrich, Marx and Boyle, 1993; Rieber and Matzko, 2001; Rieber *et al.*, 1998; Tsui and Treagust, 2004). Play has received increased attention as a learning activity (Barab *et al.*, 2005; Rieber, 1996; Rieber *et al.*, 1998; Sutton-Smith, 1997). For Rieber (1998) the concept of play is an activity that has potential to address the cognitive and motivational dimensions of learning. For long considered trivial (Sutton-Smith, 1997) and hence generally ignored in the instructional field (Rieber *et al.*, 1998), play opens concepts to new thought and where incompatibilities can be dealt with (Rieber, 1996). Play is acknowledged as an important design goal by authors such as Barab *et al.* (2005), Csikszentmihalyi (1979), Rieber (1996) and Rieber *et al.* (1998). Sutton-Smith (1979) notes the following relationship between play and learning:

> "To play with something is to open it up for consideration and choice. Play opens up thought. As it proceeds it constitutes new thought or combinations of thought." (p. 315)

In terms of theoretical framework of Vygotsky (1978) play creates broad zones of proximal development: within the context of make believe play one may perform above everyday abilities; separation of thought from actions and objects promotes abstract thinking. Csikszentmihalyi (1979; 1990) studied the experience of playfulness in adults which he has referred to as flow. He proposes that play may be an individually or culturally structured form of experiencing flow.

Games represent a space for play (Csikszentmihalyi, 1990). 'Gameplay' is the activity of the player within a game and refers to challenges in simulated environment (Rollings and Adams, 2003). The game becomes a vehicle for authentic tasks (Quinn, 1994; Squire, 2003a) and provides opportunities for participation in communities of practice (Bruckman, 1998; de Castell and Jenson, 2003). Here players are presented with simulated worlds that are not just about isolated facts or skills but embody social practices and learning by doing (Shaffer, Squire, Halverson and Gee, 2004). They function as constructivist microworlds incorporating cognitive apprenticeships.

To summarise, the key focus has been on engagement of the learner in challenging activities: hard fun, serious play, serious games but not easy learning.

2.5.2 Narrative Adventure Games

For many authors adventure games represent the best format for learning reflecting contemporary theories of learning. Rollings and Adams (2003) describe them as:

> "...an explorable area containing a variety of puzzles or problems to be solved. Solving these problems opens up new areas for exploration or advances the story line in some way, giving players new information and new problems to solve."

Narrative is central to how we learn, understand and experience the world (Bruner, 1986, 1990; Polkinghorne, 1988; Schank, 1990). Polkinghorne (1988) notes that through the use of narrative individual actions and events are made comprehensible by clarifying their relationship to the whole to which they contribute. Narrative thus serves to contextualise events and structure our experience in a meaningful way. Similarly, the game stories provide a context and structure for a player's actions, providing a meaningful and engaging experience (King and Krzywinska, 2002; Rollings and Adams, 2003).

Narrative plays a central role in adventure games. Indeed it is the narrative-richness of this genre that gives it a potentially greater educational utility than other computer games which only emphasise drill and practice (Quinn, 1994) leading them to be described as *exploratory microworlds* (Quinn, 1994) or *edventures* (Amory, 2003). A number of authors such as Jonassen (1999), Duffy and Cunningham (1996) and Perkins (1991) note that narrative forms the foundation in constructivist learning environments such as anchored instruction, situated learning, problem based-learning, and goal-based learning. In these examples, authentic problems are embedded in a context. Squire (2003a) notes how in good educational games, narrative events 'situate the activity, defining goals, constraining actions, provoking thought and sparking emotional responses as students struggle to solve complex authentic problems - narrative constraints shape action and become part of student understanding of domain. Of particular importance to genetics is that narrative functions as a substitute for direct experience (Jonassen and Hernandez-Serrano, 2002) and supports the student in understanding how to use knowledge in terms of real world actions. In other words, to develop an experiential understanding of otherwise abstract principles (Schank, 1994).

Considering their educational potential, Amory, Naicker, Vincent and Adams (1999) explored the popularity of adventure games with students. Research was initiated to identify the game type most suitable for learning and which game elements students found most interesting or useful. Results suggested that students preferred adventure (Zork Nemesis) and strategy (Red Alert) games to the other types (first-person-shooter, simulation) with Zork Nemesis ranked as the best. Students perceived game elements such as logic, memory, visualisation and problem solving as the most important to play adventure games. Such elements are integral to adventure games and are also required during the learning process. Amory *et al*. (1999) concluded that adventure games provide the best foundation for developing teaching resources - "a superior mechanism to entice learners into virtual environments" – a conclusion shared with (Quinn, 1994) and (Dempsey, Lucassen, Haynes and Casey, 1996). While narrative provides a useful and unifying tool in approaching the design of learning environments there remain a number of challenges for the design of educational games which are discussed below.

2.5.3 Challenges For Design And The Use Of Games

Despite their potential for engaging learners, challenges do exist for the effective use of games for learning. Research opinion on the effectiveness of games as tools for learning is (limited &) mixed (for reviews see (Randel, Morris, Wetzel and Whitehill, 1992)) with few differences between games and traditional instruction having been reported (Dempsey, Lucassen, Gilley and Rasmussen, 1993; Gredler, 2004a; Randel *et al.*, 1992). This is considered in the context of game research literature.

Gredler (1996; 2004b) highlighted the lack of well designed research studies: a focus was on anecdotal reports and perceived student reaction, sketchy descriptions, weaknesses in design and measurement; comparing games to classroom practice, failure to consider student differences, and no details on student interaction. Studies on the effectiveness of games have relied predominately on a comparison of games and traditional instruction based on test scores (Randel *et al.*, 1992). More importantly however is what Gredler (1996; 2004b) notes as a limited focus on pedagogy. Generally, there has been little consideration of aligning learning theories and games: games were initially characterised and used within a behavioural learning theory paradigm as much of educational technology was resulting in mainly drill and practise games: characterised as being linear, tutorial style and employing extrinsic fantasies (de Castell and Jenson, 2003). Such games therefore suffer from a failure in the use of fantasy and integration of challenges .i.e, how game elements can effectively support learning - the intended fun and play are not being evident. Games however offer far more engaging possibilities which highlights the need to define or classify the elements that constitute the game being used and consider how these elements support the learning process. Only recently have authors such as Amory (1999, 2001), Quinn (1994, 1998), Rieber (1996, 1998) and later Gee (2004) and Squire (2002) discussed games in terms of contemporary learning theory. Quinn (1994) takes the view that games themselves are not educational but rather support the implementation of educational goals, a view echoed by Reeves (1995) in referring to technology as a 'vehicle for pedagogical dimensions we wish it to carry'. It is rather the pedagogy technology enables that ultimately determines its effectiveness and worth not the technology, and in terms of the current discussion, games.

In summary, the above arguments highlight that to employ games does not guarantee learning. Rather, games leverage aspects of good learning principles which must be understood and employed in an appropriate manner. There are many examples of poor educational games in both commercial and academic contexts, which suggest the importance of a detailed level of discourse on both games and game design. To underline this Gredler (1996) has highlighted the need for effective game design models for games. This requires an understanding of how does one balance educational outcomes with games elements.

2.5.4 Towards a Conceptualisation of Games

Despite the potential afforded by games for learning, the challenge for educational game designers is balancing design tensions between meeting learning objectives and creating engaging learning environments (Kirkley and Kirkley, 2005). There appears to be little synthesis in the literature over the means of achieving this in terms educational game design models with (Shaffer 2005) noting that no effective design models existed. A number of game design models have been proposed. For example, the models of Quinn (1994; 2005), the Game Object Model (GOM) (Amory, 2001; 2006), Game Achievement Model (GAM) (Amory and Seagram, 2003) and the Experiential Game Model (Kiili, 2005). The following discussion will focus on the GOM and GAM.

2.5.5 Design of Narrative Spaces

Amory, Naicker, Vincent and Adams (1999) and Amory (2001) have proposed the Game Object Model (GOM) which builds on guidelines from Quinn (1994) and conceptualizes educational games in terms of pedagogical and game components by describing their relationships to one another. Pedagogical components are represented by abstract interfaces and game elements by concrete interfaces. With reference to Fig 3.1 the Game Space contains the Visualization Space which, in turn, includes game Elements, Actors and Problem Spaces. 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. Tasks and activities are conceptualised at the abstract pedagogical level of the GOM, and implemented through concrete features such as the Game Elements which represent a diverse array of options to the designer. Rather than a design tool the GOM provided a foundation for understanding the relationships between game elements as well as the details thereof. The Game Achievement Model (GAM) was proposed to illustrate the process of designing educational games through an emphasis on the relationship between play, story and learning (Amory and Seagram, 2003). The GAM highlights the importance of learning objectives which serve as the foundation, thereby functioning to guide and structure the design process.

The GAM is notable in defining game elements in terms of spatial parameters, i.e. scene definitions (visualisation space) which describe the details of all elements within the game world which will achieve the learning objectives. This emphasis on the environment reflects an acknowledgement of the spatial nature of game stories. Indeed Jenkins (2002) introduces the concept of spatiality in games and shifts the focus of stories to an environmental one where game designers are considered as narrative architects rather than storytellers. "Game designers don't simply tell stories; they design worlds and sculpt spaces". The game space, where the play occurs becomes a storytelling space used to support and implement ideas of the narrative and therefore the organisation of spatial features in games is important in creating the game as a narrative experience. The importance and potential usefulness of the GAM lies in structuring this development process and aligning pedagogical aims and game elements so that the appropriate environments are created to support the intended activities and so realise the learning objectives of the game. Game designers might therefore approach the design in terms of creating spaces for players' activities, using the constraints of the environment to shape these activities into a richly engaging learning experience where learners may explore and discover information as they seek to solve the challenges before them.

In so doing this research project presents the opportunity to reflect on and refine this design process through an analysis of the assumptions and activity of the game designer and compare that with what the learner (player) experiences. Activity theory will be used as a framework through which to characterise this.

2.6 Aims and Objectives

The current investigation formed part of an extended game research initiative which has already determined preferred game types and game elements, as well as identified a set of genetics misconceptions. It involved the design, development and evaluation of an educational game entitled *Food for Thought* which was conceived as one of the portals of the *GammaKhozi* learning environment being developed by the Virtual Learning Spaces Project (VLSP).

The aim of this research project was to address student misconceptions in the learning of genetics through the design and development of an educational computer game, to gain an understanding of the effective use and processes in the design of educational games in order to extend the understanding of the appropriate use of computers in the promotion of higher order thinking and problem solving skills.

To achieve this aim the following objectives were defined:

1) Evaluate the effectiveness of the game design process using the GAM (current design models), identifying challenges and reflecting on lessons learned to contribute to the body of knowledge guiding educational game design.

2) Evaluate the game in terms of content, design, interactivity and user opinion in terms of addressing genetics misconceptions.

The study was divided into the following stages:

1) The design and development of story and puzzles using the Game Achievement Model (GAM) through an iterative reflective process.

2) The creation of game resources which included using 3D modelling tools to create virtual sets which were used to generate the game resources encountered in the game.

3) Evaluation of game story, problems and environment in terms of content, design, interaction and user reviews.

CHAPTER 3: GAME DESIGN AND DEVELOPMENT

3.1 Introduction

The previous chapter introduced the difficulties of learning genetics and the potential of games to engage learners in addressing them. The challenge for designers however is how to develop educationally appropriate games that engage the learner. One approach to the conceptualisation of this challenge has been the Game Object Model (GOM) (Amory, 2001) which provided the foundation for the Game Achievement Model (GAM) (Amory and Seagram, 2003) upon which the design work for the current investigation is based. As described in the previous chapter the GAM uses a set of learning objectives as the foundation to guide the design process and achieve the pedagogical principles of the learning environment. The design of the game environment aims to engage players in the process of seeking and information and solving challenging problems by providing a space to explore and access information in different and interesting ways relating to both the story and content associated with the knowledge domain.

This chapter presents the methodology used in the design and development of the game *'Food for Thought'* within a developmental research perspective. It describes the story, puzzles and environment that was created; reflects on the use of the GAM in the design process; in addition to other issues that arose during this time. The discussion is organised around the following key areas: story (narrative), puzzles and graphics.

3.1.1 Narrative tools for games

The benefits of narrative to learning have been discussed earlier. The role of narrative in games is a controversial one where the implication is one of an obstacle to gameplay and reduces the active role of the player (Costikyan, 2000; Juul, 2002). While it is important to acknowledge that stories are not part of every game this view neglects modern theories of new media (Newman, 2002). Narrative does however not force a player into a passive state. Lindley (2005) has argued that: "The plot is not something delivered to the player, but something actively created by the player in interaction with the game system." Players engaged in narrative comprehension are far from passive but rather reconstruct their experiences. Given the close relationship between play and games it is interesting to note the relationship between play and narrative in contrast to the perceived opposition of the two. In research on cognitive development Feldman (2005) considers play and narrative to share the concept of mimesis which thus becomes a form of meaning making and learning. Rather than labelling all narrative passive one should consider how it is used in the game context. There are diverse ways in which narrative can be used especially when designing educational games and what the intended learning objectives may be.

Narrative serves the very important functions providing a context and structure for challenges and problems (gameplay) within the game world. Relevant contexts are important, e.g., intrinsic fantasy is a more effective way of using the motivational aspect of fantasy than an extrinsic one (Malone, 1981a; Rieber, 1996) and supports the argument for 'integration' where narrative goals are closely aligned to problems within the environment (Quinn, 2005). Learning in context is key and becomes more meaningful when they are intrinsically related to the problem and content domain. The structural function of narrative serves a scaffolding role focusing challenge and thus alleviating potential boredom or being overwhelmed (Mallon and Webb, 2005) Too much structure however and the result is a linear constricted experience in which the player feels no sense of agency in an environment may be perceived as contrived or constricted. Conversely, too much flexibility hinders the ability to build tension and drama.

A challenge for the designer therefore is to balance the two: *player agency versus the need for a sense of make-believe, drama and scaffolding*. When background narrative information, such as details of characterization or event history, is interspersed with play activities or presented in small snippets, or perceived by the players as potentially useful for their gameplay, they enjoyed the use of narrative (Mallon and Webb, 2005). In fact there is evidence that players want some pre-programmed control devices, such as episodic structure, linearity, restrictions, and direction. Players desire some pre-structured linearity, in the sense of not having access to certain areas, until they have the skills and resources to deal with or utilize the experience: Furthermore it is the “illusion” of choice and control, not its actuality, which is important to participants.

Structure is provided by story models. An example of a specific model of narrative form (Mallon and Webb, 2005) commonly used in computer games is the three-act restorative structure, borrowed from literature, drama and film (McKee, 1999).This structure has a beginning in which conflict is established, playing out the implications of the conflict, and is completed by the final resolution of the conflict. Each act culminates in crisis. This is an effort to frame the player’s experience into coherent goal based activities. The resulting act definitions of the GAM guide the plotting of the story through the space. Act objectives were defined to guide the achievement of learning objectives and maintain overall story structure. All games have a beginning and end and therefore have a linear nature. This structure is typical of adventure games – a form of open structure where story elements associated with spaces, in the form of game story (Lindley, 2005). The three act structure is commonly implemented by designing a high level framing narrative to frame the game experience as a whole with the dramatic arc being completed when the player finishes the game (Rollings and Adams, 2003). At this level, the story is not usually considered interactive since key scenes or plot points may typically be achieved through cut scenes; rather at the lower level of game structure a series of smaller scale conflicts and challenges, puzzles to be solved, clues and keys must be found in order to progress is where the player is most active and considered to be most interactive (Ryan, 2002). Players may thus explore and experience the game world in a non-linear fashion at this level while still enjoying the higher level structure afforded by a framing narrative. (Lindley, 2005; Salen and Zimmerman, 2004). The story follows a quest story (Neitzel, 2005). The story is shaped by the environment which is discussed in detail in the next section.

3.1.2 Environmental architecture

The players' experience is a spatial one (Carson, 2000). A player's experience of a story within a game environment is of course determined by the design and layout of that environment. The game environment provides a context for challenges and story in four ways (constraint, concealment, obstacles and exploration). Ludic spaces (Adams, 2003) frame challenges, curiosity establish goals and thus support gameplay. Narrative spaces are created through the setting, atmosphere, through environmental storytelling. Jenkins extends this by stating that structuring the game space can give different narrative experiences – the world becomes an information space awaiting discovery – a form of embedded narrative. The environment can be structured so that areas are 'off limits' to players until they have solved certain problems and this therefore provides the facility to impose some structure of the story. Environmental storytelling employs the game environment as a narrative space. Concepts such as: cause and effect, familiarity, contrast, texture, theme (Carson, 2000a, b, 2004) are used to achieve such narrative spaces.

Story tools have predominately been discussed in terms of the backstory and cutscenes (Dickey, 2005) from which much of the criticism of narrative as interruption arises. There are other ways to conceptualise this. Findings also suggest a number of ways to advance the narrative with the play (Mallon *et al.*, 2005). While some criticise cutscenes as being an interruption to play others consider cutscenes integral to gameplay (Klevjer, 2002) and proposed another way of viewing it by identifying two components of game narratives: fictive worlds which represent the narrative context, and story events which are the game incidents which occur within the fictive world. Salen *et al.* (2004) have noted that too often the fictive world is taken for granted as a generic background for plot events. The events of the game story are made possible by the existence of the larger fictional world. The story events also serve to inform the fictive world in terms of fictive worlds and story events. In doing so, story can move beyond 'backstory' as a brief background to the game to something which adds richness to the game space, or story as sequences of video but rather tools to inform the entire game experience (Salen *et al.*, 2004).

There are a number ways of presenting and arranging puzzles. Kim and Pajitov (2000) present a number of options, one of which is a metapuzzle. A hierarchical puzzle arrangement also allows multiple goals for the learner (non-linear).

3.2 Method

The GAM (Figure 1) provides a design framework comprising three main stages as follows: game definitions; act definitions; and scene definitions. The review of each puzzle during the design process was based on: story plotting; puzzle and story; puzzle relationships to one another. The game story was based on the relationship between the learning objectives, problems (puzzles), and a general premise (story). The story development began with (Step a) general game definitions determined by learning objectives and a general premise which provided a foundation upon which to develop. A broad structure for the layout was specified and approached in terms of story events which could be assembled into a cohesive whole. The learning objective definitions served as a check with which to compare emerging story with learning objectives. The premise was refined and developed through the GAM stages (Step b) as acts were defined according to desired act learning objectives and story obligations, followed by scene and puzzle development (Step c). The story went through a number of iterations especially to incorporate the presence of puzzles and environment. It is this interdependent relationship between the problem or challenges and story context that bears emphasis.

3.2.1 Game definitions: Definition of learning objectives and story outline

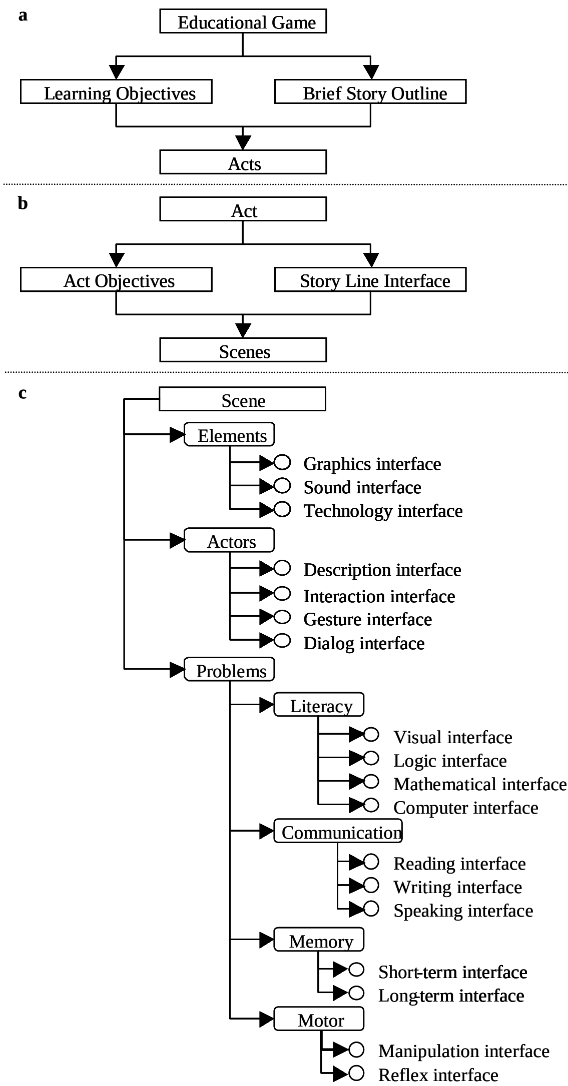
The first phase was to develop an appropriate story that would serve as a vehicle for learning genetics concepts. A set of learning objectives was initially developed from a variety of sources and are presented in Table 1. The identification of specific learning misconceptions in first year students at the University of Natal (Ivala, 1999) provided the basis for developing a set of learning objectives, which were supplemented by current literature on genetics misconceptions. These served as a foundation for the process of story, puzzle and environment design. Additionally the learning environment provided an opportunity to introduce supplementary information and current issues in genetics to enrich the learning experience. These included the role of technology and in particular genetic technology, the role of ethics in the behaviour of professional scientists, the nature of science and its role in society as well as our ability to think

Table 3.1. Learning objectives for *Food for Thought* which served as a foundation for the process of story, puzzle and environment design

1	Understanding of chromosome structure, especially the relationship of DNA replication to structure • identify a replicated and unreplicated chromosome (acknowledge the change in morphology linked to cell division) • identify different representations at different scales
2	Understanding of gene concept and its role in determining physical characteristics • define what is a gene • describe the relationship between gene and allele • describe the relationship between genotype and phenotype
3	Understanding of the concept of ploidy • define what ploidy is • identify what determines changes in ploidy
4	The process (sequence) of mitosis and its function (context) in the lifecycle • identify the stages of mitosis (sequential knowledge) • state the function of mitosis (context; inputs and outputs)
5	The process (sequence) of meiosis and its function (context) in the lifecycle • identify the stages of meiosis (sequential knowledge) • state the function of meiosis (context; inputs and outputs)
6	Appreciation for the role of science and research, modern applications of genetics and technology • introduce ethics • introduce new technology • implications for society

Table 3.2. *Food for Thought* Act objectives

ACT I	ACT II	ACT III
Establish sinister mood: a break in at the facility	Develop subplots (learn of Doctor's backstory from various sources)	Reversal: unexpected discovery of vaccine
Ask a dramatic question: what has happened?	Vaccine information thread (key to unlock access to get the vaccine)	Resolve the subplots concerning Doctor and her past
Introduce characters and story word (viral outbreak; Doctor working on vaccine)	Find key/ Unlock access to storeroom (act climax)	Unlock access to get the vaccine
Find key/ Unlock access to hidden laboratory (act climax)		



Game definitions
Learning objectives and story premise.
Story events arranged into a narrative structure: 3 acts
Puzzle relationships.

Act Definitions
Act objectives for each act.
Story events for each act arranged into scenes

Scene Definitions
Elements, Actors and Puzzles
Graphics concealment, challenge
Define and develop puzzles

Figure 3.1. The Game Achievement Model which consists of 3 primary stages. Annotations have been added on the right to expand on what the outcomes of each phase were.

critically about issues and consider multifaceted nature thereof. All design decisions were based on realising the learning objectives in an engaging and interesting context – it thus became critical to be thorough in the definitions thereof. This served as a foundation for a loose plotting of a number of key story events which were structured into what would serve as the game's framing narrative with a brief description for each act. The focus of this process was on the activities in which the player might be involved during the story events and how these might serve a narrative function. Furthermore, these narrative goals would be used as a basis for incorporating the challenges into the game story i.e. an *alignment* between narrative goals and puzzles. Although not stated in the GAM, puzzles were initially conceptualised at this stage to ensure that the game story would be support the necessary challenges required to achieve the learning objectives. This process involved developing a high level draft concept of the puzzles and their relationships to one another. The story however remained the focus as it represents the narrative structure that will provide a unifying context for the activities of the game. In some instances story events were created to support a particular puzzle.

3.2.2 Act definitions

The initial story events for each act were developed in greater detail and assembled into a structure with a number of act objectives as the outcome (Table 2). Story events were associated with spaces within the game world and these determined the scenes required for each act. In addition, elements were moved into different acts based on the learning objectives and story demands. The use of the term 'scene' was in the context of fulfilling a story function i.e. the traditional definition rather than representing a specific location. However due to the spatial nature of games the 'scene' would take place at a specific location in the game world. Puzzles were arranged into a conceptual hierarchy with selected puzzle solutions associated with specific story events; and the relationships between puzzles finalised. To avoid forcing players through a single path of exploration, *gateway* puzzles were used to introduce each new act. These were key puzzles chosen to conclude acts and bring a sense of dramatic closure whereas other puzzles could be solved irrespective of what puzzles had been solved previously. Thus the framing narrative served to structure the narrative on a macro scale whereas the placement of individual puzzles within the act created a local narrative tension as they were encountered.

3.2.3 Scene definitions

Having established the narrative requirements of each act and for each scene therein, the scene level details (environment) were now defined in terms of the elements present in each scene. These would serve as the vehicle through which players would experience the game story and so serve an environmental storytelling function. This approach was extended to the details of the puzzles which were designed with the aim of integrating them with the story.

The design of problems is implied in the development of the story in the GAM but not made explicit. The development of the puzzles occurs concurrently with that of the story and subplots. Puzzles began as paper thumbnails which proceeded to 3D model and a programmed puzzle interface. From the Game Object Model (GOM) problems (puzzles) consist of a number of components: story, feedback, goal formation and completion, content (resources), context and here special attention was given to goal formation and completion. Puzzles were conceptualized to function logically in game world and match narrative goals. Attention was given to sufficient goal and feedback for players. In doing so they would contribute maintaining player engagement.

From an environmental design perspective (which may influence the design of the problem as well), it is important to design locations with puzzle based ‘machines’ or objects that have a function that might serve a purpose other than what the player can do with it e.g. the difference of being about to use a virtual computer to just look for specified code or imply that other things may be possible with it. The emphasis was on the building meaning into the design and extend what Murray (1997) refers to as an ‘active creation of belief’. This relates to a motivational aspects of player control (even if only an illusion) and building an endogenous fantasy that is immersive and does not jar when conspicuous objects appear in environments for no apparent reason other than to provide an obstacle. A development of this argument is that the environment should appear as if its presence is not solely for the player but that the environment may continue to exist beyond the confines of the game. This is not always possible but should be aspired to facilitate an engaging experience. Puzzles are most satisfying when they have dramatic appropriateness, and serve as a way of increasing our belief in the virtual world (Murray, 1997).

In order to support a player’s perception of choice, some interfaces supported a number of different actions instead of using a single puzzle interface to perform one function with a single object. In addition to contributing to a sense of player agency, players would be required to reflect on what they were doing as opposed to merely placing an object in the matching slot.

3.3 Game descriptions

A detailed description of the story, scenes and puzzles is included in this section. The scenes that comprise the world are listed in Table 3.3 and the puzzles are listed in Table 3.4.

Table 3.3 Scenes from *Food for Thought*

ACT I	ACT II	ACT III
Sc1. Grand Hall	Sc1. Meiosis Optics	Sc1. Storeroom/ Growth room
Sc2. Gene Library	Sc2. Lab	
Sc3. Ploidy / Life Galleries	Sc3. Gene Library	
Sc4. Mitosis Optics	Sc4. Life Galleries	
Sc5. Passage		

Table 3.4. Puzzles from *Food for Thought*

1	Chromosome representation puzzle (Login)
2	Diploidy puzzle (Gift)
3	Haploidy puzzle (Lab complex access)
4	Mitosis sequence puzzle (Sequence)
5	Meiosis sequence puzzle (Sequence)
6	Mitosis context puzzle (Gift)
7	Meiosis context puzzle (Gift)
8	Sample identification (Vaccine access code)
9	Gene concept puzzle (Genecards)
10	Punnet I puzzle: Meiosis and symbol derivation: lifecycle context (Zygote)
11	Punnet II puzzle: genotype to phenotype, symbol derivation (Storeroom access)
12	Storeroom puzzle (Vaccine access)

3.3.1 Story outline

The final story is described as below:

The story is set amidst the prevailing climate of public uncertainty over the implications and impact of biotechnology and genetically modified organisms. A number of outbreaks of viral infections have decimated many small communities which are now under quarantine. Dr Khanyi Msizi heads a small private research facility leading the development of a vaccine in partnership with the National Department of Health. The project was recently re-assigned to be administered by a former colleague of hers, Dr Xolani Mhlongu, giving rise to an element of tension.

Her belief is that the vaccine should be made freely available. Though her motivation is sincere, she is perhaps naive. Publicly, Dr Mhlongu voices concern over the safety of the vaccine under development yet privately is focussed on its lucrative potential. A decade earlier they worked as colleagues in one of the countries most promising Medical Research Programs. However, following the death of her child a few hours after birth and struggling with her misplaced guilt, she let go of her research career. Her guilt was compounded by a prevailing misconception within her family that the responsibility lay with her. She subsequently closed down the promising research program for which she was principal investigator. For an ambitious career driven individual as Xolani Mhlongu this proved an unacceptable affront to his career path. He was left without a very promising position while having to live up to his own unrealistically high expectations. His bitterness shapes his motivation to succeed at the expense of Dr Msizi.

While attending a Parliamentary review committee on biotechnology to present their promising results on their vaccine development, there is a break-in at Dr Msizi’s lab. The museum and research facility houses the vaccine her team has been developing. Considering the devastation the virus has already wrought its success is considered to be critical. However, to control access to such an item might be considered even more important. The player is required to find the vaccine before it falls into what could potentially be the wrong hands.

The search for the vaccine requires discovering where it is stored within the research facility. The player must use laboratory work, understanding of processes associated with inheritance to discovering just what happened to Khanyi in her grief.

Having located where the vaccine is stored, the player discovers the vaccine exists in both an edible and traditional form. It also appears that they have been beaten to the prize and that joy of revenge is being savoured. The player learns that a press release had been prepared by Dr Msizi to announce the successful creation of an edible vaccine that will undergo thorough testing. In order to detect it a fluorescing protein has also been inserted so it glows in the dark. However, instead of accessing the (traditional) vaccine in the storeroom the player finds a note left by Mhlongu. Here he reveals how he managed to get to the vaccine and will be cleaning out the facility – these will be no record of her work and Dr Msizi will be left humiliated especially following her announcement. He ends the note with a flippant “Turn off the lights before you leave”. However, the very prize the player seeks is right in front of them. If they do indeed flip a nearby light switch the room is left dark and the fluorescing plants containing the vaccine are visible right before their eyes. While Mhlongu believed he would retain control of the vaccine by stealing it his supposed victory is subverted by the very notion of the edible vaccine which is in the open, exposed and freely available.

Picking up a plant brings the game to a close.

3.3.2 Scene descriptions

A general overview of the game environment is presented with brief explanations and descriptions of the approximately 14 locations.

Exterior House and Grand Museum Hall

The player begins the game on the front porch of what appears to be an old house. The facility is a national monument, a historic colonial mansion house on Durban’s Berea that now houses a museum of genetics to which a complex of laboratories has been added. To facilitate a moody atmosphere as well as justify the deserted nature of the location, the game events take place on a chilly evening. The converted house provides a logical setting for the themes and activities in the story.

Upon entering the house the player moves to the grand hall of the museum (Figure 3.3a) – a double volume space dominated by a Shona style stone sculpture of a metaphase chromosome. The interior of the house has been renovated yet still retains the spirit of the old building where a mix of old and new styles aims to support the creation of an environment with a sense of history and reality, as well as elements which may be familiar to players. These include Victorian design cues recalling the historic architecture of Durban and iconic motifs of the Durban Natural History Museum. Inspiration was also derived from motifs associated with genetics to provide players with an appropriate thematic context. Ransacked drawers and overturned lamps along with low key lighting make use of the environmental storytelling principle of *cause and effect* to suggest a break in and provoke the question: what has happened here. The stylised chromosome sculpture

Figure 3.3 presents scenes from *Food for Thought*, namely the (a) Grand museum hall with associated (b) map and layout; (c) the Gene library is a gene information resource housing access to the research facility’s database in addition to a number of displays listed here (d) and explored in more detail in Figure 3.4; (e) the Life Gallery is themed around the life cycle with a variety of sculptures representing the associated stages; the Mitosis Imaging lab provides access to cell cycle and virus information to the player – there is a similarly designed Meiosis Imaging lab where a complementary design provides a visual link with its associated sibling puzzle; the main research lab provides an environment for players to engage in laboratory techniques in addition to the detective work in the game. Finally (h) show the basement which also functions as a storeroom for biological material.

serves to illustrate the relationship between DNA and chromosomes in terms of scale and morphology.

Gene Library

The Gene Library (Figure 3.3c) is a source of information on the gene and its development as a concept. The Durban Natural History Museum once again provided a point of reference through the wood panelling and displays in addition to the influence of elements of Charles Mackintosh's natural stylized forms informed DNA and natural motifs. Low key lighting was once again employed to draw attention to the important points of interaction. The player can access historical museum displays akin to walk-in dioramas, each of which reveal part of the story of the development of the gene concept.

The five displays (Figure 3.5) are organised around the following themes:

i) Cellular Inheritance: here players explorer the ideas of cellular inheritance (mitosis) and the key ideas of Virchow,

ii) Particulate Inheritance: ideas of Mendel where hereditary information was not blended together but rather occurred as discrete units inherited from both parents,

iii) Chromosomal Basis of Inheritance: chromosomes identified as carriers of hereditary material,

iv) Linked Inheritance: the Fly Room of Thomas Hunt Morgan and his ideas of genes on the chromosomes; mutations

v) Molecular Inheritance: ideas leading to the identification of the structure of DNA from its discovery as hereditary material to.

Each display provides an opportunity in an experiential manner for players to step back in time to key stages in the development of the gene concept and see how the ideas have changed. The displays also serve to present the development of science concepts as building on one another. Information is presented as notes and comments from researchers and players can read notes from key researchers and historical research laboratories and locations have been referenced. This does not however aim to provide an in-depth commentary of the complexity associated with the gene and what is now a much discussed and disputed concept but rather expose students to an engaging introduction. The juxtaposition of mitosis and meiosis, a theme that will be developed throughout the game, is also introduced in the displays. The placement of the displays raised issues relating to *navigation* and *avoiding player disorientation*. Players are also able to access a database of

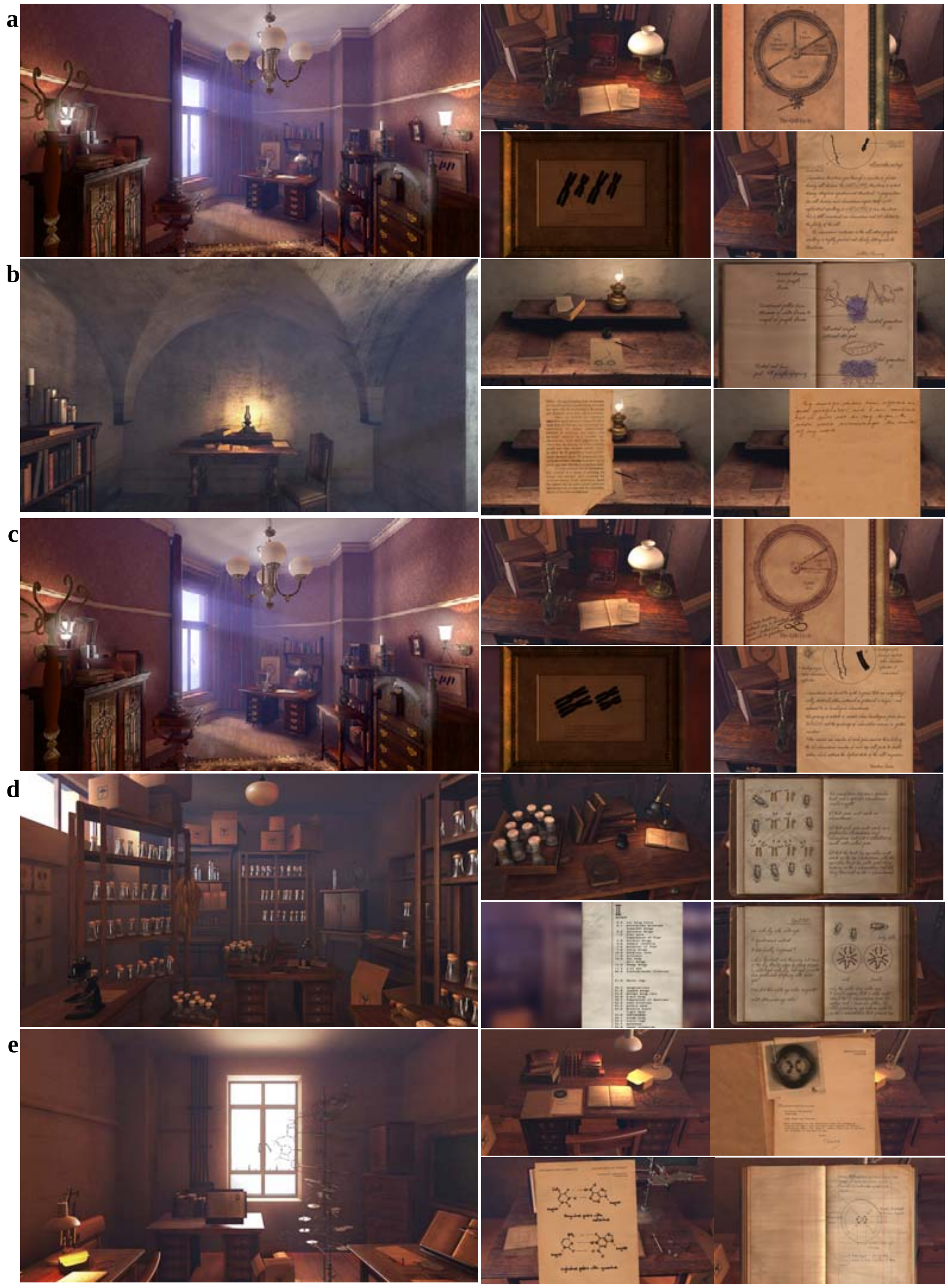


Figure 3.5. The displays in the Gene Library are presented here (a) Cellular Inheritance (b). Particulate Inheritance (c) Chromosomal Basis of Inheritance (d) Linked Inheritance and (e) Molecular Inheritance. Each display includes extensive resources in terms of notes and video

gene information. It is this database which also functions as the interface for the Gene Concept Puzzle thus serving as both the basis for a puzzle interface as well as fulfilling a function in the game world.

Life Gallery

The Life Gallery (Figure 3.3e) is a space dedicated to pieces of art referencing stages in the life cycle. A number of patterns and themes are introduced here which are to be linked together later in the game. Elements of the Doctor's story are interwoven into the elements on display which are thus used to fill in parts of the story. The player can explore information on the life cycle and the associated processes in their functional context, namely: mitosis, meiosis and fertilization: each stage representing a puzzle interface namely the Haploidy and Diploidy, and the Mitosis and Meiosis Context Puzzles.

Laboratory Complex

The Laboratory Complex (Figures 3.3) exists as part of a new wing attached to the original building of which three parts are accessible. This presented an opportunity to introduce a design contrast to the older building. Tossed books on the floor are used to indicate a level of disturbance and avoid a narratively neutral environment. Focused lighting is used to direct the player to the PCR and DNA sequencer they will be required to find. Posters provide supporting content as well as extra information. There is a note on vaccines in the laboratory with a purple colour intended to reference the link to fluorescence the player will discover at the end. Additionally, the theme of mitosis and meiosis as similar yet different processes is reflected in the design of the two adjoining 'imaging' rooms where these concepts are interrogated. The aim of this is to support the comparison and contrast of the two processes in the design of these rooms and in doing so extend their juxtaposition which was initiated in the Gene Library displays and extended in the Life Gallery. In the Mitosis Imaging Room the use of colour, i.e. the red light, is used to establish a thematic thread relating to the virus and this is reprised in the Gene Library.

Glass doors are used to show additional locations and yet also conceal them to lend structure to the game experience. Players however can see the laboratory to be accessed facilitating goal formation within the player to find an entrance. Players test their sample and get the sequence which will be used to probe and find DNA sequence and information. Items are also available to be picked up for later puzzles.

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Storeroom

An old basement now houses the growth room storage chamber (Figure 3.3h) which the player is able to access having solved all the game puzzles. Narratively, the basement storeroom functions to conclude the story threads and resolve the game goal i.e., the player gets the vaccine, or doesn't. There is a reversal here where the player is led to believe all is lost. However upon carefully reading what is said, the prize is revealed.

3.3.3 Puzzle descriptions

The development of the puzzles will now be discussed in terms of their context, visual design and solutions. In some cases more than one puzzle has been used to address a concept. For the sake of discussion puzzles are described in relation to concepts they address, not in terms of the sequence they might be solved in the game. There are twelve puzzles in the game which are named according to the concept they are designed to address (where applicable).

3.3.3.1 Chromosome representation puzzle

The structure of chromosomes and its relationship to DNA is poorly understood. Students are therefore unable to comprehend the meaning of the difference between unreplicated and replicated chromosomes which has implications for understanding other genetics concepts. These difficulties may be attributed to students having to deal with multiple and conflicting representations of chromosomes. The aim of this puzzle (Figure 3.6) is thus to address learning objective (1) by engaging the player in an activity that requires an understanding the relationship of the various representations (line and symbols, nucleotides, banding patterns and helical representations).

Story context

The library in the museum complex houses a database of genes and their related products which the player may use to find out more about the location of the vaccine. However in order to gain access to these resources the player is required to login to the museum network.

Puzzle design and appearance

The puzzle interface is represented by a touch screen monitor in the Gene Library. It was designed to give players an opportunity to show their understanding of what various representations meant as well as to specifically challenge what they understood the various representations meant by allowing them to select the corresponding structure represented in a

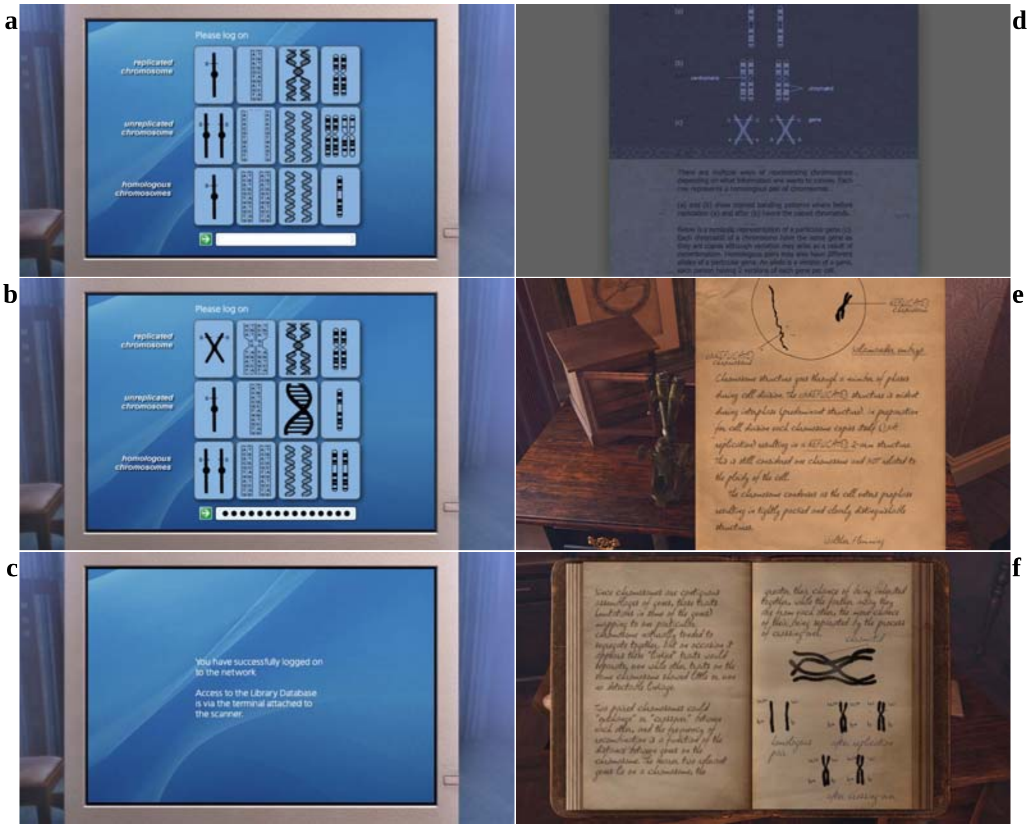

Figure 3. 6. The Chromosome representation puzzle. The player is required to login to the existing museum network. The puzzle interface is presented in Figures (a)-(c) with example of the supporting information included in Figures (d)-(f). The player is required to match the appropriate chromosome descriptor (homologous chromosome, unreplicated chromosome and replicated chromosome) with its corresponding style of representation (line and symbol, nucleotide level, banding pattern and helical representation).

different manner, i.e. players were able to express what they understood the relationship of replicated chromosome to an unreplicated chromosome to be but not just in terms of a lines and symbols but how the corresponding representations in terms of nucleotides, banding patterns and helix related to it. As the goal is to access the network, players are greeted with a ‘please login message’ when they approach any of the monitors available.

Puzzle solution

The player is required to match the appropriate chromosome descriptor (homologous chromosome, unreplicated chromosome and replicated chromosome) with its corresponding style of representation (line and symbol, nucleotide level, banding pattern and helical representation). Feedback in the form of dots filling a form (as in a login password) is given when correct representations are chosen. Upon successful completion a message notifies the player of a successful login.

3.3.3.2 Ploidy puzzles

Misconceptions about the concept of ploidy are common. This is directly addressed with the haploid and diploid puzzles by placing the concept in its functional context within the lifecycle, and referencing chromosome morphology which is mistakenly assumed to determine ploidy. While they are separate puzzles, they form a functional pair in providing an opportunity for a student to articulate their understanding of the concept, and are therefore discussed together.

Story context

The Life Gallery houses a number of sculptures which have a thematic relevance to the lifecycle. Two of these are function as interfaces for the Diploidy and Haploidy puzzles: part of a system for hiding access to the storeroom and lab. They have been assembled as part of Dr Msizi’s stone sculpture collection where they are presented as stages in the lifecycle in the life gallery. Both guard items which will help the player on their quest. The solutions relate thematically to the function of the associated lifecycle stage.

The Haploidy puzzle is part of a thematic activity series associated with meiosis, namely understanding the ‘vocabulary of chromosomes’ and their relationship to ploidy. Upon solving the puzzle the player has access to engaging with the sequence of meiosis then finally meiosis in context. Solving of the puzzle, by virtue of its placement, acts as a *gateway puzzle* ending Act 1 as the player moves into the passage and a new undiscovered environment, i.e. the laboratory complex. The Diploidy Puzzle forms part of a larger problem of finding a number of ‘gifts’ and relating the stages to their context within the lifecycle for the Punnet I Puzzle. Solving the puzzle results in the player receiving an item referred to in a clue as a ‘gift’. This is used in a later puzzle to represent the stage of fertilization which establishes the diploid state of a cell.

Puzzle design & appearance

Similar designs are juxtapositioned for the two puzzle interfaces which were designed as pieces of art placed in context within the Life Gallery. The Diploidy component, due to its relationship to fertilization, incorporated the abstract forms of two parents; while the Haploidy component referenced the infinity symbol as a comment on the nature of genetic information. Spheres are used to represent cells and this is repeated for related puzzles thus introducing thematic relationships in the design, i.e. the Punnet puzzles where the object picked up from this puzzle will be used.

Although the exact outcome of solving the Ploidy puzzles must be discovered by the player, there are a number of methods employed to guide the goal formation aspect of these puzzles using written labels as clues as well as having a hidden location visible from another viewpoint (the laboratory) to suggest that a puzzle may provide access. This form of guidance is critical to support the player in developing goals, otherwise there is the possibility of the exercise becoming one of something that ‘they have to do’ without any curiosity as to why.

Puzzle solution

Both puzzles are designed to encourage learners to use their current (naïve) understanding and, if present, misconceptions. They therefore have an opportunity to attempt to solve the puzzle by applying their current understanding which is supported by the design of the puzzle interface. The feedback, along with supporting information resources (content) is intended to scaffold the player. Supporting resources are embedded within the environment. This includes detailed interactions to discover the relationship of chromosome structure to cell cycle and the origin of the 2DNA chromosome, and the role of meiosis and fertilization as affecting ploidy. If the player is unable to solve the puzzle there are resources to be examined. The solution is not transposable but rather requires interaction with the puzzle – interpreting the information in the light of content they would have encountered.

i) Diploidy

The goal of the player is to create a diploid (2N) state i.e. to highlight pairs of similar structures. Therefore by matching the ‘chromosomes’ that are present in pairs the player progresses through

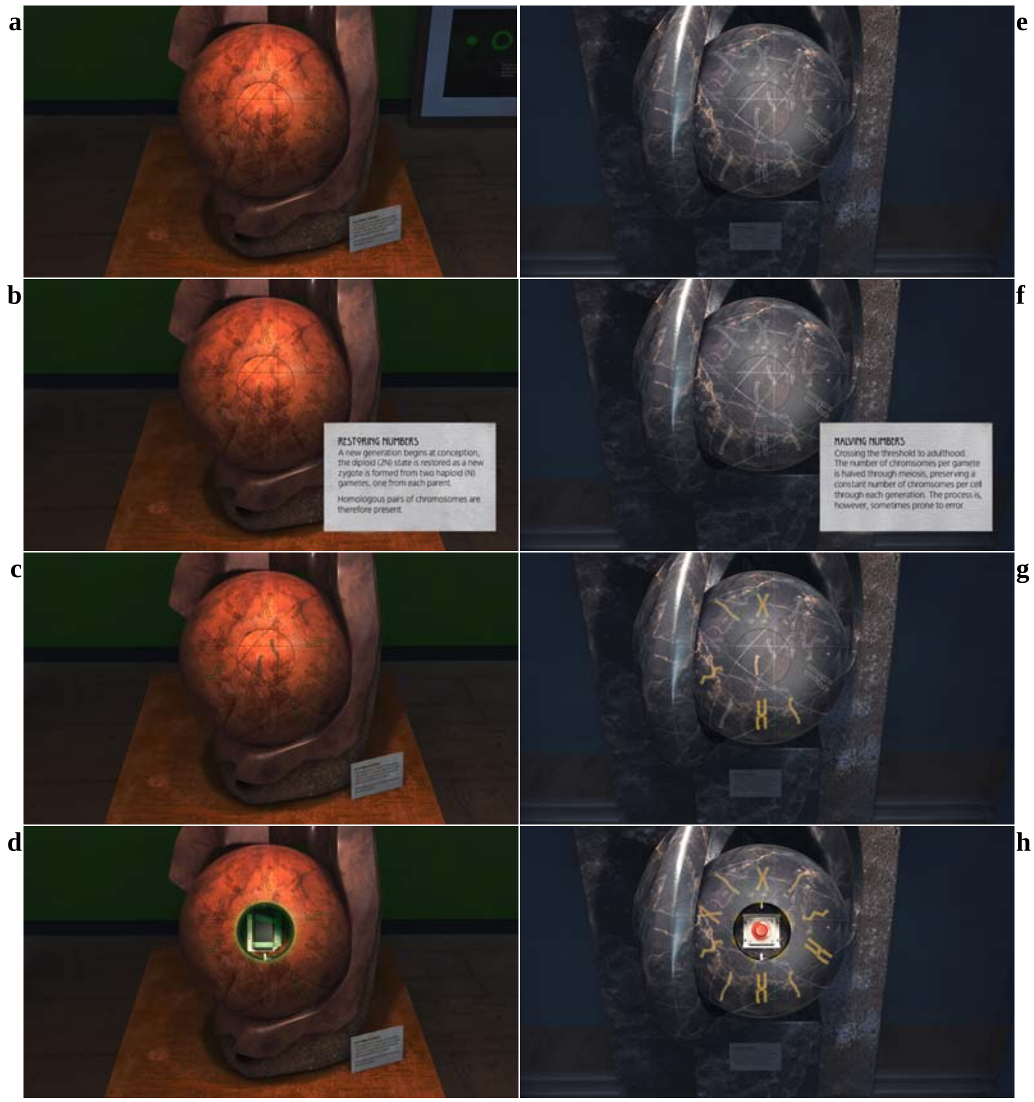

Figure 3.7. The Ploidy Puzzles are presented together for comparison. Both guard items which will help the player on their quest. The goal of the player in the Diploidy puzzle on the left is to create a diploid (2N) state i.e. to highlight pairs of similar structures. Stages in solving the puzzle are presented in (a) the neutral state with (b) clue; (c) the solution that shows the matched homologous pairs of chromosomes establishing a 2N state. Solving the puzzle results in the player receiving an item referred to in a clue as a 'gift' (d). This is used in a later puzzle to represent the stage of fertilization which establishes the diploid state of a cell. The corresponding Haploidy puzzle on the right challenges the player to create a haploid (N) state. Stages in solving the puzzle are presented in (a) the neutral state with (b) clue; (c) the solution that shows one member of each pair selected to complete the haploid state. Upon solving the puzzle the player has access to engaging with the sequence of meiosis then finally meiosis in context as a secret passage in revealed after the (h) button has been pressed.

the puzzle. The goal is to match pairs but opportunities exist for players to try and incorporate replicated structures which they may think influences ploidy – an expression of a misconception - which will not be successful as there are no homologous pairs of replicated chromosomes present. The importance of feedback from the interaction is stressed here which guides the player and informs what combinations might or might not work. Each correct pair is confirmed by a green illuminated line, which one the correct ones are selected completes a ring and opens to reveal an item taped to the back of the cover.

ii) Haploidy

The corresponding haploid part of the puzzle challenges the player to create a haploid (N) state. Instead of selecting pairs one member of each pair is selected to complete the puzzle. A progress bar illuminates if one member of the pair is selected but if both are selected the puzzle reverts back to a neutral state. Given the absence of persistence of a highlighted selection the player is required to remember or take notes in order to solve the problem. Upon completion the sphere opens to reveal a button to be pressed and so a hidden passage is revealed which leads on to the Meiosis Sequence Puzzle which is a step in solving the Meiosis Context Puzzle.

3.3.3.3 Mitosis sequence puzzle

The events of mitosis are not well understood. The events are often considered as static stages within the process. The aim of the puzzle is to address student understanding of the sequence of events occurring in mitosis and consider the context of these events as they relate to the cell cycle (Figure 3.8). The puzzle emphasizes the origin of 2DNA chromosome during the events of mitosis and serves to extend the theme of dealing with this aspect in the Ploidy puzzles. The concept is directly addressed by following a tagged sequence though the division process with an emphasis on chromosome movement. The player is provided with an opportunity to place the stages in sequence based on short animations and text descriptions.

Story context

The laboratory complex houses an imaging room where the research team is working on the virus and microscopy is used for viewing cellular processes. It is here that the first flashback of Dr Msizi can also be viewed. In the context of the research team studying the virus, parts of the cell division sequence of an infected cell has been simulated from captured images. The puzzle represents the player’s first encounter with the virus. The pattern derived from the sequence of mitosis is used in the gallery to obtain one of the ‘gifts’ mentioned earlier, continuing the flow from mitotic sequence to mitosis in context.

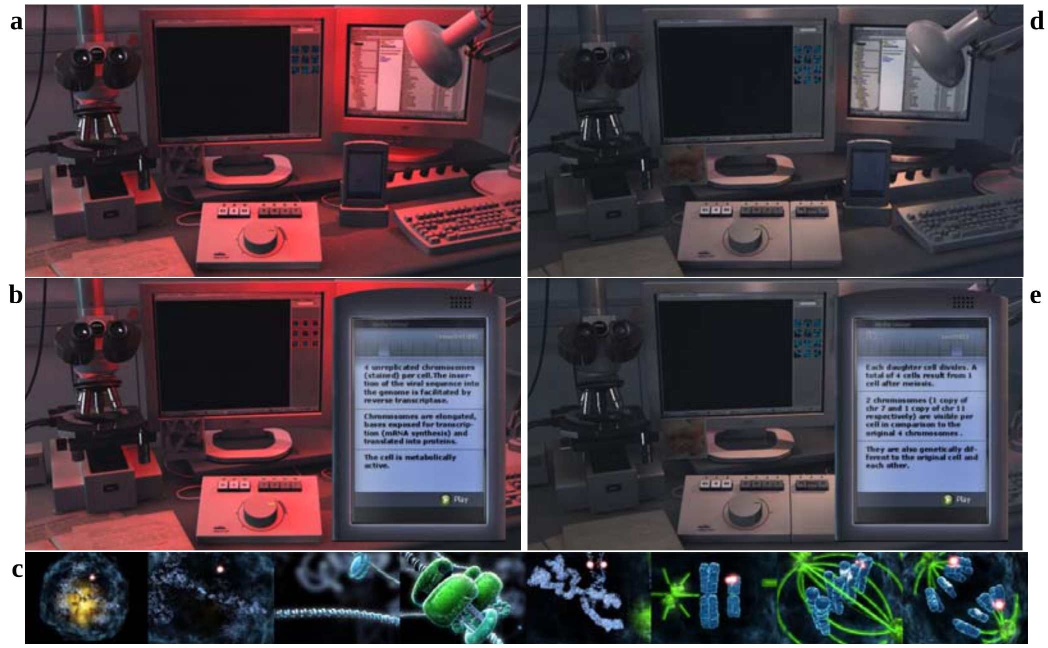

Figure 3.8. The Mitosis (a) and Meiosis (d) sequence puzzles are presented together for comparison. The goal of the player in the Mitosis sequence puzzle on the left is to place the stages of mitosis in sequence. Each stage consists of (b) a short animated sequence and associated text description of the corresponding events. Once the stage is matched the button is lit and the sequence is played back. The thumbnails also create a pattern which is for use in the Mitosis context puzzle. The entire animated sequence is presented in (c) The corresponding Meiosis sequence puzzle on the right challenges the player to place the stages of meiosis in sequence. Each stage consists of (e) a short animated sequence and associated text description of the corresponding events. Once the stage is matched the button is lit and the sequence is played back. The thumbnails also create a pattern which is for use in the Meiosis context puzzle The pattern derived from the sequences of these processes is used in the gallery to obtain one of the 'gifts' mentioned earlier, continuing the flow from process sequence to process in context.

Puzzle design and appearance

The puzzle interface resembles lab equipment in the form of an imaging station and microscope. Although not functional accurate the microscope serves to as an allusion to authenticity. Mitotic sequences are selected via a device which resembles a PDA. The stages are described in detail together with a short video. The insertion of a tagged viral sequence – indicated in red - is used as the thread to follow through the process i.e. one copy which becomes two. The stages of the cell cycle are represented by buttons labelled with the appropriate stage as read in order from left to right, i.e. G1 S G2 P M A T. These letters act to suggest the goal of the puzzle. Thumbnail images on the screen represent each stage and are highlighted in red when each of the sequences is selected. Their position and sequence are used in a later puzzle and is designed to reference a related puzzle in the Life Gallery. The stages are described as well as shown in a simple form in the Mitosis Displays. Information is included in the laboratory to support the solution, i.e. virus replication, cell cycle stages. These resources are presented as graphs and micrographs to height the sense of authenticity.

Puzzle solution

The player is required to place the stages of mitosis in sequence. Each stage consists of a short animated sequence and associated text description of the corresponding events. Once the stage is matched the button is lit and the sequence is played back. Upon completing the ordering of the sequence the player can view a detailed representation of the events of mitosis which builds on the simplified view seen earlier in the Mitosis Display. The thumbnails also create a pattern which is for use in the Mitosis context puzzle.

3.3.3.4 Meiosis sequence puzzle

The events of meiosis are also not well understood. The aim of the puzzle is to address student understanding of the sequence of events occurring in meiosis and consider the context of these events as they relate to the cell cycle (Figure 3.8). The concept is directly addressed by following tagged sequences though the division process with an emphasis on chromosome movement. The puzzle also serves as a comparison with mitosis due to their similarities in design and presentation. In addition, the narrative context serves to address the context of meiosis and the impact of errors in this process. The player is provided with an opportunity to place the stages in sequence based on short animations and text descriptions in a similar way to that which they encountered in the related mitosis puzzle.

Story context

The laboratory complex houses a number of imaging rooms for viewing cellular processes. The events of meiosis are being studied in the context of Dr Msizi's history with Trisomy 18 and her role as supporting those who are experiencing similar difficulties. The story of her loss as result of a disease related to the process of meiosis is developed. Thus the puzzle became a meaningful part of the story and learner experiences the problem and concept in terms of its function and implications of its importance – part of the reason for the failure to understand the significance of meiosis. The pattern derived from the sequence of mitosis is used in the gallery to obtain one of the 'gifts' discussed earlier, continuing the flow of activity to addressing meiosis in context.

Puzzle design and appearance

The puzzle interface resembles that of the Mitosis puzzle in order to juxtapose the two concepts. Meiotic sequences are selected via a device which resembles a PDA. The stages are described in detail together with a short video. A tagged allelic pair is used as the thread to follow through the process i.e. one copy which becomes two. The stages of the process are represented by buttons labelled with the appropriate stage as read in order from left to right. The player may use either representation to place them in sequence on what resembles a mixing desk with the letters for each stage on a button namely G1 S G2 P M A T M2 A2 T2 These letters act to suggest the goal of the puzzle and are similar to those presented in the corresponding Mitosis puzzle, i.e. G1 S G2 P M A T. These letters act to suggest the goal of the puzzle. Thumbnail images on the screen represent each stage and are highlighted in red when each of the sequences is selected. Their position and sequence are used in a later puzzle and is designed to reference a related puzzle in the Life Gallery. The stages are described as well as shown in a simple form in the Meiosis Display. Information is included to support the solution as well as extend the narrative of Dr' Msizi's backstory.

Puzzle solution

The player is required to place the stages of meiosis in sequence in a manner reflect the actions of the corresponding Mitosis puzzle. Each stage consists of a short animated sequence and associated text description of the corresponding events. Once the stage is matched the button is lit and the sequence is played back. Upon completing the ordering of the sequence the player can view a detailed representation of the events of meiosis which builds on the simplified view seen earlier in the Meiosis Display. The thumbnails also create a pattern which is for use in the Meiosis context puzzle.

3.3.3.5 Mitosis and meiosis context puzzles

The role and function of mitosis and meiosis is poorly understood. This is addressed by the Mitosis and Meiosis context puzzles which aim of the puzzle is to challenge the player to consider mitosis in the context of the lifecycle in addition to reflecting on the stages of the process. These puzzles (Figure 3.9) will be described together due to their similarity and they way in which they work together.

Story context

As stated earlier, the gallery in the facility hosts a number of sculptures which have a thematic relevance to the lifecycle. There are also missing sculptures to suggest that a break-in has occurred at the museum. The pedestals that remain represent mitosis and meiosis in the context of the lifecycle and it is these which contain items which have been hidden by Dr. Msizi as a security measure and which the player will use in their quest to obtain the vaccine. By solving each puzzle the player receives one of the ‘gifts’ to be used in the Punnet Puzzle.

Puzzle design and appearance

The puzzle consists of two independent components whose design is related. Similar designs are juxtapositioned for the two cell division processes in order to challenge players to make a choice as to which pedestal corresponds to a particular sequence. Buttons represent stages and are visually related to the Mitosis and meiosis sequence puzzles from where they derive their origin. Labels serve to suggest the goal of the puzzle.

Puzzle solution

The player reflects on the appropriate process and chooses the corresponding sequence. Upon entering the sequence and pressing the ‘>’ key, the gift is revealed.

3.3.3.6 Vaccine sample identification

Puzzle provides an opportunity to introduce players to laboratory techniques to give them an introduction to the role of technology in genetics. It is not intended as an exact reproduction of the procedures but rather an opportunity to present players with a version in which they can appreciate the role of the technologies without having to deal with the minutiae as this was not the objective of the puzzle.

Story context

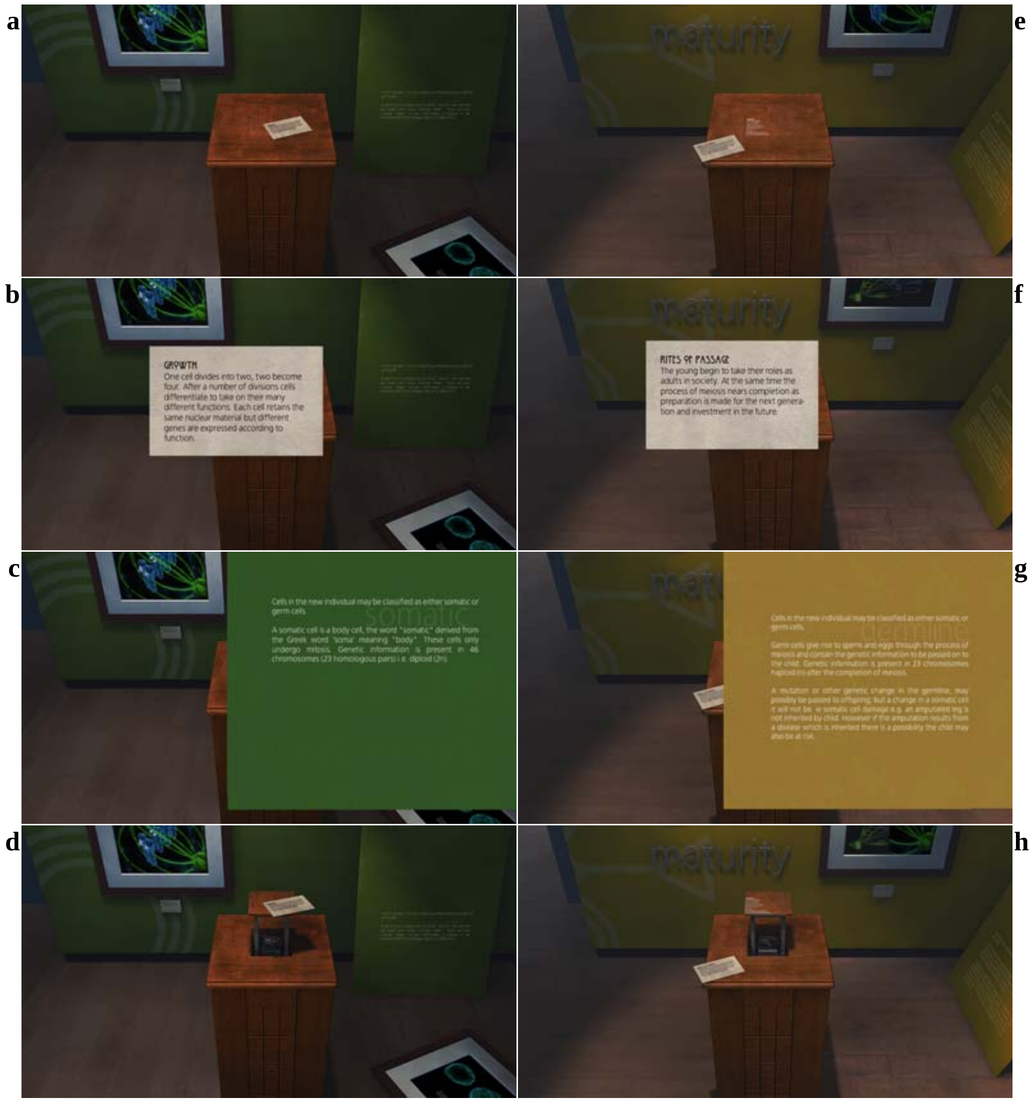

Figure 3.9. Mitosis (a) and Meiosis (e) context puzzles are presented together for comparison. Similar designs are juxtapositioned for the two cell division processes in order to challenge players to make a choice as to which pedestal corresponds to a particular sequence. Buttons represent stages and are visually related to the Mitosis and meiosis sequence puzzles from where they derive their origin. Labels (b) (f), information (c) (g) serve to suggest the goal of the puzzle. To solve each puzzle the player reflects on the appropriate process and chooses the corresponding sequence. Upon entering the sequence the gift is revealed (d) (h).

The sample facilitates a narrative goal of identifying the its composition which extends from its discovery to the culmination of the activity where the sequence is scanned and matched against the database. Used this way, the sample facilitates the introduction of story, providing something to pick up and which in turn acts as a stimulus for exploring what to do with the sample. A colleague of Dr Msizi has sent a modified sample of the viral sequence for her, something which is alluded to in one of the flashbacks. With the Doctor away however, and a subsequent break in it would appear that the sample has been taken. However, a hidden chamber protects the secret which acts a key to unlocking the location of the vaccine.

Puzzle design and appearance

Familiar elements were used in the design to give a sense of authenticity. Designs of DNA sequencers and PCRs formed the basis for the designs of those appearing the laboratory. They were however modified to facilitate an additional element graphical feedback for the player while in the device was in use to illustrate what was happening to the sample.

Puzzle solution

The puzzle consists of a number of stages (Figure 3.10).

i) Pick up sample

Near the museum entrance is a package which has been broken apart. An eppendorf tube holder appears to be empty but after clicking on a hidden panel, a compartment opens to reveal the sample for the player to pick up.

ii) Amplification

The sample requires amplification before sequencing (this is suggested if the sequencer is approached first). Using the controls on the panel the sample tray is opened, the sample added and then ‘start’ is selected.

iii) Sequencing

After amplification, the sample may be sequenced by insertion into the DNA sequencer. The player receives a printout to be used as a probe for information in the library database in the Gene Library.

Figure 3.10 Vaccine sample identification Puzzle. The puzzle consists of a number of stages (a) pickup sample, (b) (c) amplification and (d) (e) (f) sequence and finally (g) (h) probe for relevant information. The cataloging code for the vaccine is uncovered here.

iv) Probe

The player uses the scanned sequence obtained from the DNA sequencer to locate information on what turns out to be the virus, and learn the location of the virus. There also is additional information on the mechanism of action relating imagery back to the mitosis lab puzzle where the virus imagery of red was introduced. The style of information presentation is designed to reflect that of searching an authentic gene bank. This forms the end of a task complex beginning with the eppendorf sample of the viral DNA, amplifying and sequencing it, and then using this sequence to probe the database for related information, much like a researcher might use a tagged sequence to search a genome.

3.3.3.7 Gene concept puzzle

A lack of understanding the structure of chromosomes has implications for the understanding the gene concept. Students are unable to comprehend what is meant by the more abstract concepts of genes, alleles, genotype and phenotype. The aim of the Gene concept puzzle (Figure 3.11) is to address student understanding. Specifically it addresses: i) the path from gene to protein; ii) ‘dominance’ and variant alleles; and iii) the concepts of genotype and phenotype. It builds on and is related to other puzzles. Furthermore an understanding of what a gene is, is critical for an understanding of other concepts.

Story context

The library in the museum complex houses a database of genes and their related products which the player may use to find out more about the location of the vaccine. Having gained access to the network the player can now see some of the actions they can perform in searching for information. They are however required to enter nucleotide sequence which, having done so, allows them to probe for information which will be used to solve the puzzle from which they will obtain the desired *genecards*. These items, or *genecards*, represent specific allelic variants of genes which are to be searched for in the database. The activity serves as a metaphor for the process of probing a genome. The *genecards* are specifically related to Dr Msizi’s personal story which runs as a narrative thread throughout the game. The items are used in the Punnet II puzzle as one of four *gifts* or components to be brought to the statue housing the puzzle.

Puzzle design and appearance

The puzzle interface resembles equipment with which players might be familiar. The design includes a number of monitors and a scanner to scan sequences for the player to explore information on genes through a combination of text, video and images which are accessible at any

Figure 3.11 Gene concept puzzle. A genetic sequence can be used to probe for information about that sequence. The player uses sequences from the hidden lab found scattered on the floor. The function of this puzzle was to obtain the 'genotype' component for the final puzzle using information about (a) sickle cell anemia and (b) cystic fibrosis, one of four components to be found. Examples of the information players can find is depicted in (e) to (h) which includes information about the gene and variant alleles, the protein that the gene is used to code for, the resulting normal and disease phenotypes in form of images and short video sequences. Each is labeled with a number which the player must use to find the appropriate genotype component (i.e. genecard) by relating the path from gene to protein to phenotype (b) (d). This is repeated for the other disease genotype. To find the appropriate genecard both genes are involved and both proteins are expressed – both are required to be selected.

time. Here they can probe different aspects of real sequences, to see them as a sequence of nucleotides that produce a specific protein; and that alleles are alternative versions of a gene. The content and puzzle overlap as an effort to try and blur lines between puzzle and information required to solve it. The puzzle deals with interrelated concepts: the path from gene to protein, relationship between homologous chromosomes in terms of alleles and dominance, deal with multi levels from genotype to phenotype. The puzzle serves as a metaphor for locating a sequence of DNA. The player uses the scanned sequence as a ‘tag’ to search the database for information relating to it. To heighten the level of authenticity and in so doing contribute to a suspension of disbelief, the information is presented in a manner resembling an authentic search through a gene bank. In addition, imagery is presented as being sourced from a microscopes or computer simulations.

Puzzle solution

A genetic sequence can be used to probe for information about that sequence. The player uses sequences from the hidden lab found scattered on the floor. The function of this puzzle was to obtain the ‘genotype’ component for the final puzzle using information about cystic fibrosis and sickle cell anemia, one of four components to be found. The player can explore information about the gene and variant alleles, the protein that the gene is used to code for, the resulting normal and disease phenotypes in form of images and short video sequences. Each is labelled with a number which the player must use to find the appropriate genotype component (i.e. genecard) by relating the path from gene to protein to phenotype. This is repeated for the other disease genotype. To find the appropriate *genecard* both genes are involved and both proteins are expressed – both are required to be selected. In addition the word dominance is avoided as has been recommended.

3.3.3.8 Punnet puzzles

Symbol formation using Punnet squares is poorly understood. In addition the relationship between meiosis and symbol formation is unclear in the minds of many students. Furthermore the relationship between phenotype and genotype in symbolic terms is not understood. The aim of the Punnet puzzle (Figure 3.12) is to therefore facilitate the understanding of symbol formation and its relationship to biological processes, as well as an appreciation for what the results of a Punnet cross mean. The lifecycle context is used to link these aspects together. The puzzle also serves as a form of metapuzzle where the solutions of previous puzzles are brought together as the puzzle contextualizes the fertilization, meiosis and mitosis in relation to the lifecycle, genotype and influence on characteristics especially passing from one generation to another. The puzzle has multiple parts and emphasizes: the processes of fertilization, meiosis and mitosis in relation to the

a e
bc f
c g
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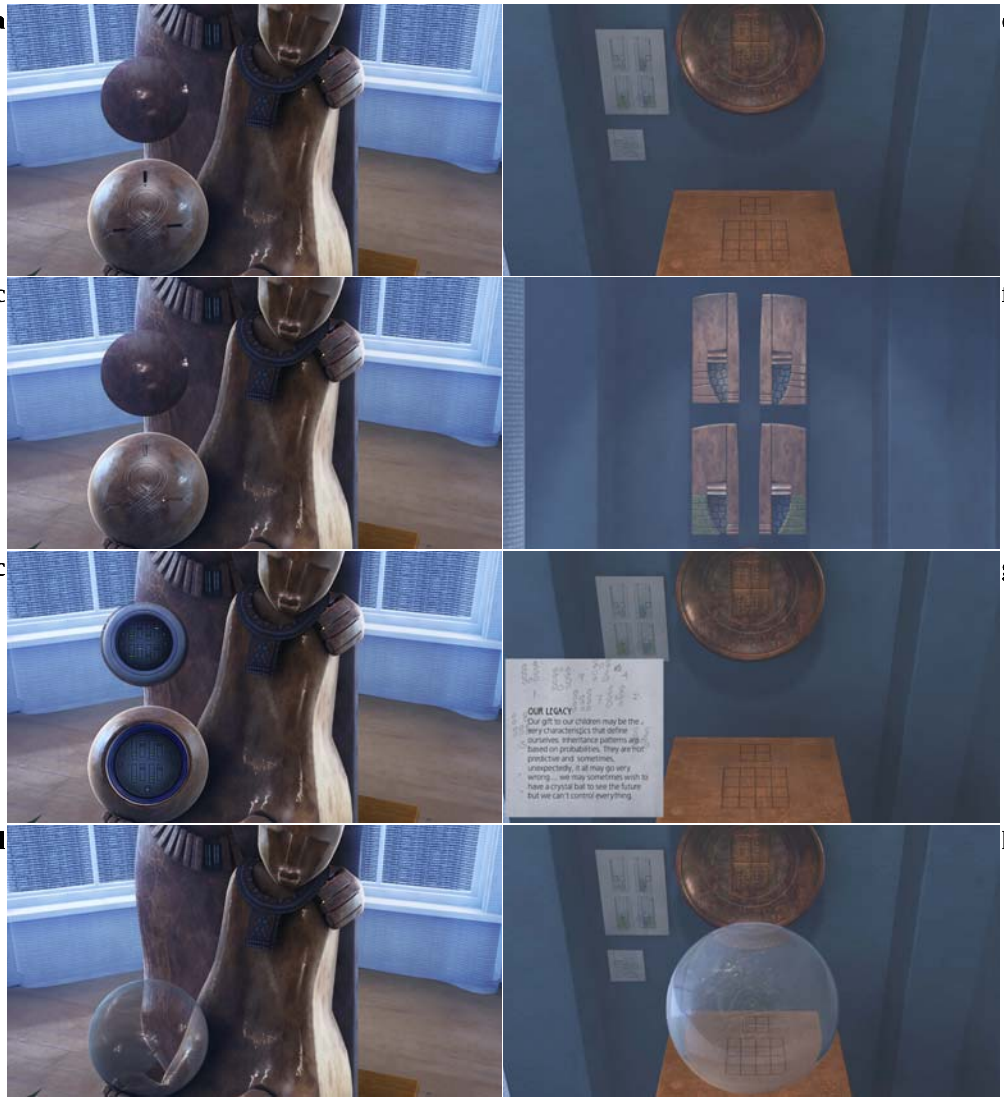


Figure 3.12 (a) Punnet puzzle in neutral state represents an element of the personal story of Dr Msizi. The puzzle has a number of stages. (b) Gift solutions representing stages of the lifecycle are placed into their appropriate positions. Gamete formation (meiosis) occurs (c) players choose the appropriate possible allelic combinations. Upon doing this correctly the male and female gametes represented by the 2 halves of the sphere merge to form a (d) zygote in the form of a crystal ball. This sphere is placed on the grid where possible genotypic combinations are matched to the corresponding phenotypes represented by the (f) masks.

lifecycle, the relationship between symbol formation and meiosis (gamete formation); relationship of genotype to phenotype in terms of symbols.

Story context

The Life Gallery houses a number of sculptures which are related to the Punnet puzzle. Each sculpture represents or is related to a stage of the lifecycle. The primary Punnet interface is a sculpture of a couple representing Dr Msizi and reflects much of her feelings and personal story. The puzzle forms the Act 2 climax as the door is opened to the basement storeroom as the player learns how she bared much of the apparent blame for her child's death. A story element of hope and protection for the next generation is introduced in the form of gifts for a mythical bird and a 'lifecycle knot' symbol. These serve to guide the player's goal formation as well as add a layer of depth and emotional resonance to the puzzle. Additional aspects of this story are referenced though the Trisomy 18 genetic screening pages and a sketch of the sculpture. Upon solving the Punnet I we hear a voice over of the Dr Msizi where the reason for her extreme sadness is elaborated on: her baby was a Trisomy 18 baby and while pregnant she had to make a decision between her own life and the child's. She felt guilty about this while family saw her as the cause of the problems, not understanding the nature of the condition.

Puzzle solution

The puzzle has a number of stages:

i) Gifts

The player places the 'gifts' from previous puzzles into the context of the lifecycle represented by the motif on the sphere of the sculpture. In addition the player places the genotype to be crossed obtained from the library puzzle into the slot. This results in the options for meiosis being revealed.

ii) Punnet I (symbol formation)

The player selects the correct possible combinations for male and female gametes. If the correct combination is selected, the two gametes unite and a zygote is formed. The resulting sphere undergoes a change signaled by a green wave which references a diagram in the gallery about the action of calcium ions after fertilization. The zygote, which in the context of the Punnet square represents all possible combinations of the parental generation's genetic material, then turns transparent - in essence, a crystal ball.

iii) Punnet II (phenotypic ratios)

The player places the crystal zygote on an adjacent pedestal. Above the pedestal are four masks on the wall representing the possible phenotypes resulting from the Punnet cross. A different genotypic combination appears for each position on the grid and the player must match this with the corresponding phenotype (mask). If the 9:3:3:1 ratio is correctly derived the player hears a sound and steps back to notice that a previously hidden staircase has been revealed.

3.3.3.9 Storeroom puzzle: Obtaining the vaccine

The Storeroom puzzle represents the endgame and the player's opportunity to achieve the goal laid out during the game.

Learning objectives

Whereas the Punnet puzzle represents the metapuzzle and culmination of previous puzzle solutions the endgame puzzle uses a short code to access the vaccine; or where the vaccine should be. The learning objectives are light – a reflection on a previous code obtained after probing for virus information.

Story context

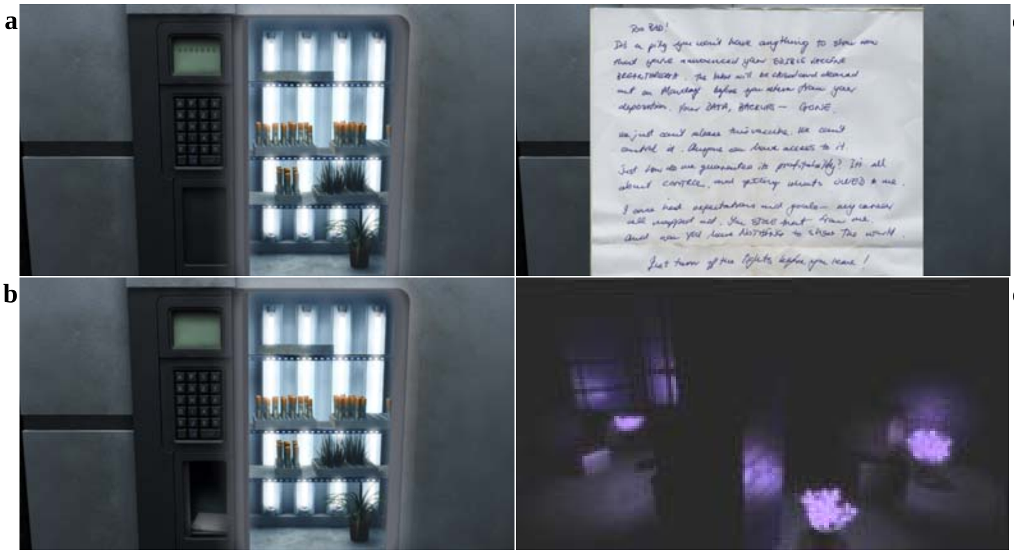
The basement houses a growth room and storage facility along with various pieces of detritus that usually inhabit basements. It provides an opportunity for concluding the variety of story threads that have been introduced during the game.

Puzzle design and appearance

The puzzle interface is designed to constrain player access the storeroom samples. The only way the sample may be accessed is through the process of entering the appropriate code or storage location and serves to extend the metaphor of uses a sequence to locate an item amid a seemingly complex plethora of data or samples.

Puzzle solution

The puzzle solution is apparently straightforward. The appropriate code is entered and the vaccine is delivered. However rather than the vaccine a note is left behind which concludes Dr Msizi's story. There is a reference to 'turning off the lights' which if taken literally, the location of the vaccine is revealed to the player via fluorescing plants which contain the edible vaccine. The player clicks on a plant to pick it up which consequently ends the game.



a c b d

Figure 3.13 Storeroom puzzle. The Storeroom puzzle represents the endgame and the player’s opportunity to achieve the goal laid out during the game. The (a) appropriate code is entered but rather than the vaccine a note (b) is left behind which concludes Dr Msizi’s story. There is a reference to ‘turning off the lights’ which if taken literally, the location of the vaccine is revealed (d) to the player via fluorescing plants which contain the edible vaccine. The player clicks on a plant to pick it up which consequently ends the game with an ending sequence which concludes the game and describes the fates of the main characters.

3.4 Game development: Creating resources

In this description of the development, the process of designing a single object will be used as a reference point for describing the different stages of the production pipeline. A virtual set was used to represent the game environment and created with the use of 3D modelling software which offered many possibilities, but did present a number of challenges which required addressing. An examination of the world around us reveals much complexity and it was this that inspired the attention to detail to deliver a believable and engaging world.

Graphics are an important component in engaging players. The emphasis of the development process was not necessarily on photorealism but rather to achieve a sense of heightened reality which was believable, engaging and immersive to lending verisimilitude to the story. To support this, the decision to use pre-rendered rather than real time 3D graphics was made.

The game environment was created using *Autodesk* 3D Max to build a 3 dimensional representation of the game space in the computer. All objects are models which are constructed. Adams (2003) refers to these objects as *ludic architecture*. An overview of the production pipeline is presented in (Figure 3.14). Sketches were used to develop concepts and provide a design which would be translated ideas into 3D models through the production pipeline: modelling, texture mapping, scene layout and lighting, rendering, assembly and coding, and testing. The process is discussed in detail below.

3.4.1 Modelling

The process of modelling may be described as the sculpting of a three dimensional representation of an object using geometric data. While a number of modelling techniques and tools were available, it was the appearance as well as function of the object in the game space that determined which would be employed. Objects that the player would interact with or inspect closely were modelling with greater detail than many of the background objects. While manufactured objects are traditionally considered to be relatively simple e.g. table use basic primitives they also may consist of complex curves e.g. lab instruments. Hence a combination of primitives as well as subdivision modelling was used to achieve results that would serve to suspend disbelief and immerse players in the believability of the game world. To manage the complexity and file size associated with the models that were created, the environment was broken up into parts where rooms were worked on as individual scenes in individual files.

3.4.2 Shaders and Texture mapping

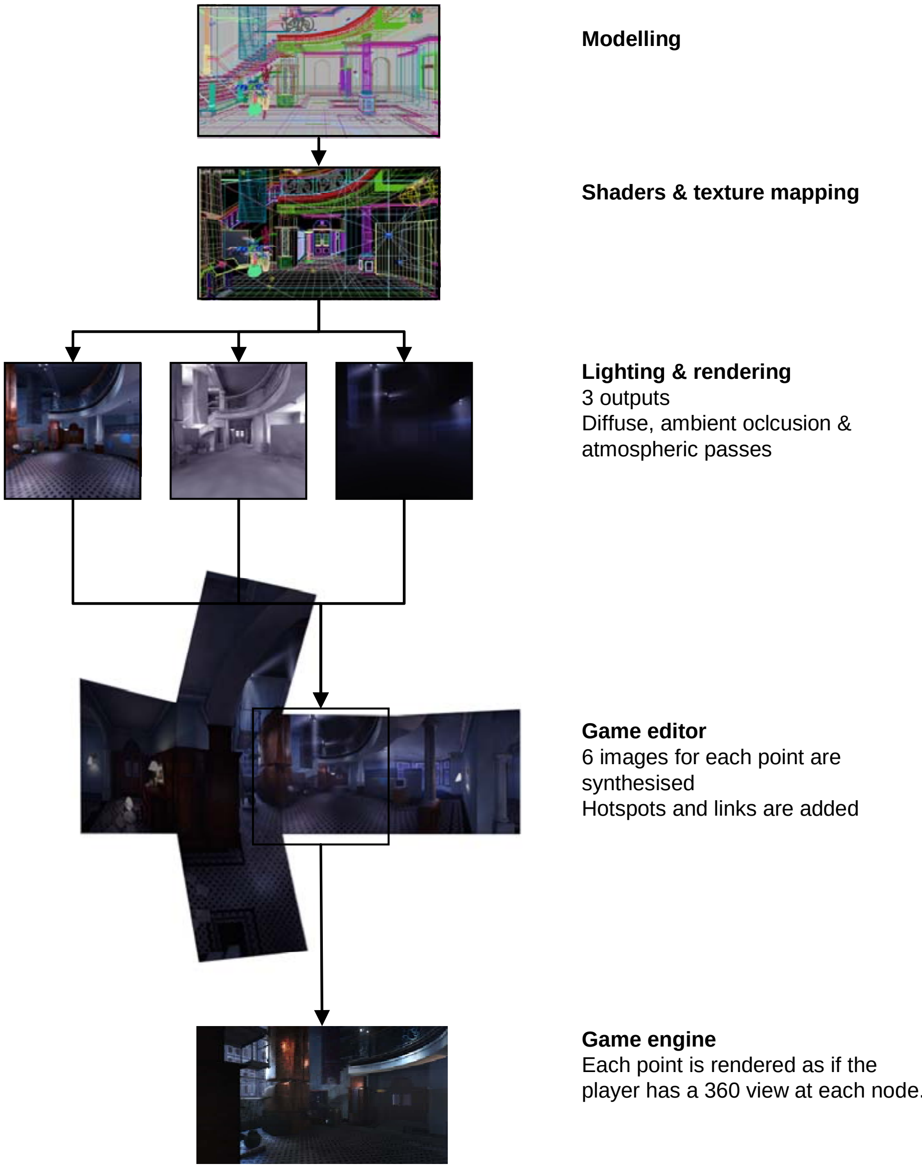


Figure 3.14. Game production pipeline

Texture mapping is a technique of applying surface detail to a model to describe qualities such as colour, shininess or reflectivity though the use of images. A common misconception attributed to texture mapping is that of merely projecting an image on a surface. There are however a myriad of characteristics one may use to add to the believability to the surfaces of objects: diffuse, specular and bump mapping to name a few. Different texture maps (images) were combined as shaders (materials) to describe the surface properties. Textures presented an important narrative tool in that they contributed to describing the elements of game world through weathering and distress in the appearance of the environment: neutral textures were avoided in favour of images built up with layers of natural weathering and complexity. A number of objects presented a challenge in creating a believable representation thereof but provided opportunities for using interesting sources to solve the problem, e.g. rice for fly larvae.

3.4.3 Animation

Animations created for the game environment ranged from short sequences of opening doors and objects to puzzles complex biological sequences.

For the flashback memories characters were animated in *MetaCreations* Poser.

3.4.4 Lighting and Rendering

Principles of theatrical lighting (Calahan, 1996; Millerson, 1991) were used to light the environment with a focus on supporting the story associated with the story. Low key lighting (high key to fill ratio) was used predominately. Three different light set ups were used for each image: a diffuse pass, ambient occlusion pass and volumetric (atmospheric) pass. The diffuse pass with primary shadows established colour depth. The lighting of the indoor scenes required the manipulation of a number of light sources, e.g. the Museum Hall scene made use of approximately 50 light sources. However the 3D Max point lights betray the computer graphic nature of the image which is a noticeable artefact that newer sophisticated programs overcome. A number of techniques were employed to retain believability. A three point light setup was employed using light arrays (grouping of lights) to achieve a style of illumination that mimicked reality more effectively than individual point sources. The second pass, or ambient occlusion pass, filled in the fine shadows which contribute to image dimensionality and depth. A public release of *Chaos* Vray was used to achieve this with textures removed and replaced by neutral gray. The resulting image was added as an overlay layer, and proved more efficient in terms of render time than if textures had been included. The third output layer was created using black materials to create an atmospheric layer of glows and fog.

Rendering is the process whereby the 3D models are translated into an image incorporating the textures and lighting. The final image output was made up of a composite of three different lighting set ups: a diffuse pass, ambient occlusion pass and atmospheric pass mentioned earlier.

3.4.5 Assembly and synthesis

Players navigate through the game space via predetermined nodes, each of which was made up of 6 camera views (front, back, left, right, up, down). A single camera view was composed of 3 images representing a diffuse colour pass, an ambient occlusion pass and an atmospheric pass. Adjacent views in some cases required some work in *Adobe* Photoshop to ensure the seamless transition between camera views. In addition due to file size and render limitations the output of scenes that has been broken up in order to work with, required compositing in Photoshop. Each node was constructed using the Game File Editor (PEdit) where each directional view, specification of linking nodes; the names of puzzles (which were created in Delphi by Professor Alan Amory), the sound commands and any video to be played were defined and combined. Each node conveyed the illusion of being able to turn 360^{o} at each node in the game environment (see Figure 3.14). The resulting *pef* files that were created were compiled into an archive from where the game engine would access them.

3.5 Reflecting on the design process

The process of design and development will now be discussed through a personal reflection on challenges that were encountered during the process of creating game environment. Activity theory will be used as a lens through which these issues can be illustrated visualised and understood in the context of the activity system around the game designer. The object of the activity will form the focus of each topic from where related components of the system will be discussed. From here specific tensions, areas of interest and implications for the educational game design process can be explored. The components of the entire designer centric activity system are illustrated in Figure 3.15. During the game design and development phase the designer (author) was required to fill and number of roles. It is perhaps a unique situation where the roles of game designer and educational designer might be separate. This was to provide a unique insight into the challenges and tensions between the elements of ‘game’ and those of ‘learning’. The details of the system are described below.

3.5.1 Design specification

There was an interesting tension between the design style of the designer and the GAM. The GAM employs a top-down approach to educational game design. The advantage of this is that the

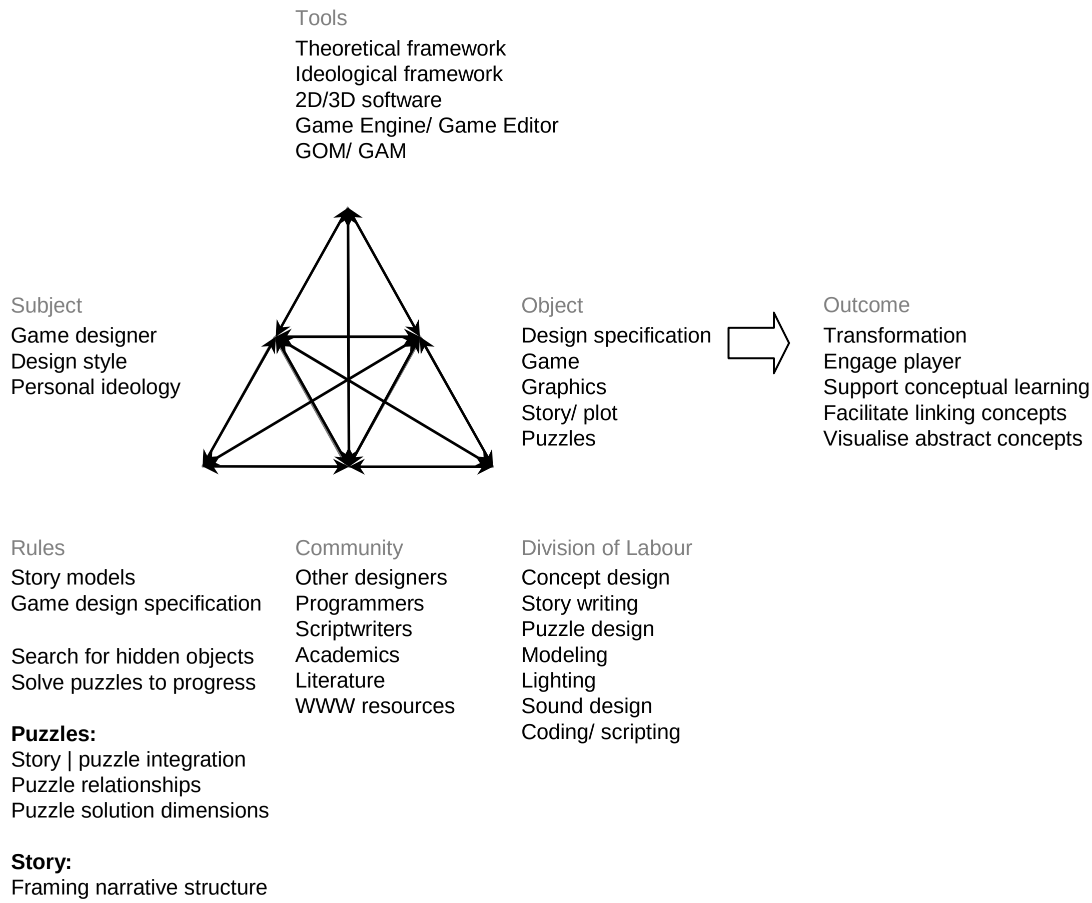


Figure 3.15 Designer activity system derived from reflection on game development process.

process is structured beforehand, categorizing a variety of different components in a very complex development and maintaining the focus of the development process. The style of the designer was however more akin to what Turkle and Papert (1991) have described as a bricoleur in his approach to the design. In contrast to a top-down planners approach, "bricoleurs have goals but set out to realize them in the spirit of a collaborative venture with the machine." Design is seen as conversation, a reflective in practice where novel ideas can brought to the fore. In isolation either approach is limited yet together the best of both worlds were brought together as discoveries in the design process were made through the reflective practise of the designer. A discovery bottom up approach to design may become an endless search especially without the constraints and organising influence of the GAM which served to constrain and focus the process on the core elements of the game, especially the learning objectives. Indeed where dilemmas and conflicts arose, the critical issue remained the educational aims of the learning environment. In this way the model was employed in a dynamic way where puzzles and story events were modified as the story and environment evolved. Criticism of games thus far have been in their lack of educational value (Gredler, 1996; 2004b) and in the absence of a rigorous design model, that is indeed likely to occur. What would benefit the GAM as a tool creative design tool would be to reference the iterative nature of the design process.

Not only does the GAM serve to structure the design process but due to its close conceptual relationship with story models, it helps to frame a meaningful game experience for players using the educational learning objectives as a foundation.

Story

The story development process was influenced by emerging relationships between components of the activity system. These included personal ideology and framing narratives.

i) Personal ideology

A designer may design the gameplay and story of a game without any conscious regard for cultural rhetoric or their own personal ideologies. However, an educational game provides opportunities to challenge stereotypes and introduce an element of transformation to the outcomes of the game playing process. While the implementation of violence as a means to success will not necessarily results in violent acts, the potential for reinforcing unacceptable behaviour exists. A conscious effort was made to address the stereotypical portrayal of woman as passive and weak hence the main character in the game is a strong female main character that embodies ethics and compassion. In addition, a prevailing theme was to introduce players to science and technology in the context of the real world. New ideas were introduced e.g., edible vaccines, to challenge learners over their own prejudices and feelings about technology yet using the opportunities afforded by stories to give these issues a context rather than cold presentation of facts.

McAllister (2004) uses an example in *Black & White* where common sense is transferred from the developers' ideological framework which included many cultural stereotypes into the game's ideology . Given the transformative potential of games, there is a responsibility for educational game designers to be aware of what they include in a game and include elements for specific reasons. This emphasises the importance of the GAM and learning objectives in guiding the design process and motivations for design choices. The aim of education is to challenge but one must also steer clear of propaganda. Care was taken to exercise restrain and provide relatively balanced arguments within the game environment. In conclusion, whether or not the game is intended as transformative, a designer should be *aware of their personal ideologies* and understand that there are alternatives.

ii) Narrative discovery

In designing a game story it necessary to consider the degree of control that is exercised over the player. The use of story for framing the game experience in a three act structure advocated by the GAM may help provide an engaging experience for the player. However, too much reliance on narrative may give the player a sense of no control and may diminish enthusiasm for the experience. The point is that as game designers there are many story models to apply and it is important to ask why a particular implementation of narrative is used. There is no single correct way of creating an educational game. Many players are not dissatisfied with the way that framing narratives function, this is partly an issue of game design quality but also the preferences of the player (Lindley, 2005). In terms of *Food for Thought*, the aim was to frame the experience in terms of *narrative discovery*. Discovery of the story was through the solving of puzzles, the outcomes of which were related to learning more of what was happening in the game environment. The player discovers through the environment what is happening and relevant sides of the debate. There were also cutscenes with flashbacks to fill in story detail. To avoid taking players out of the gameplay too much these were kept to a minimum. However, during the reviews, players requested more.

Puzzles

During the process of designing the puzzles a number of 'game rules' emerged as the designer made decisions about the creation of the game. These decisions included story-puzzle integration, puzzle relationships, nature of tasks and nature of the puzzle solutions.

i) Puzzle and story integration

A feature of the design and development process was to consider the design of puzzles during the story design process to incorporate them into a meaningful and consistent whole. Salen and Zimmerman (2004, 2005) have stated that the integration of story and problem contributes to the meaningful nature of a game, and therefore contribute to engaging the player. In the context of the game design, a case-based learning approach was useful in approaching the link between context and the puzzles. It is this link which facilitates the situated nature of the problem being in context (Bednar *et al.*, 1992). An extension of the puzzle story integration is that narrative goals were linked to puzzles to support player motivation to solve them and suggest outcomes in terms of fitting into the bigger picture of the game. Players were allowed to generate their own goals enabling them to take ownership of the problem or task. Furthermore, there is a risk of boredom if players perceive no reason for solving problem. The use of themes and related designs was intended to convey coherence in the environment. Furthermore, *Food for Thought* is not intended to be a neutral environment. An incident has occurred and thus papers are scattered, furniture damaged, and a unique melancholy punctuate the world. Through this technique (Carson, 2000a) questions are raised and challenges are brought forth. But most importantly the intention is that the problems and objects have a relevance to the world and in so doing create the intrigue and motivation for players to explore the environment and to engage them in the mystery. This highlights the usefulness of the environment as a storytelling tool and potential to use it in a close relationship with puzzles. A guiding principle of the design activity, evident in the rules of the system, was therefore to *align and integrate puzzles and story events* where possible.

iv) Puzzle relationships

In addition to the relationship between narrative and gameplay (story and puzzles), the puzzles and their relationships to one another emerged as another attribute of puzzles to be considered in the design process. Considering the interrelated nature of genetic concepts and their separation as a factor in learning difficulties, the puzzles were designed to be interrelated. This facilitated the conceptualization of puzzles as part of a greater problem solving structure and give support to a flow of activity with integrated problems that required the player to reflect on their paths to success, promoting metacognitive activity. There are a number of puzzles which are solved using information or objects from other puzzles. This hierarchical relationship between puzzles, a conceptual layout referred to as a ‘metapuzzle’ according to Kim and Pajitov (2000), represents a common game idea and serves to support motivation (develop a rising tension as challenge increases), maintain learning complexity and opportunities for reflection. Bednar *et al.* (1993) proposes a linkage to larger task complex so as to avoid inert problems without context. As stated previously the inter-relationships between puzzles is important to consider as one is able to develop a sense of meaningful action that player can undertake within the game environment and chance for players to reflect on paths to success. The player is challenged to make connections between ideas and so build a rich understanding of a concept – especially in terms of how it relates to other concepts. Thematically related designs would be important to support the player in finding links between puzzles. In addition similar designs were used to juxtaposition ideas with one another especially where processes could be compared and contrasted, e.g. mitosis and meiosis. The *relationships between puzzles* were therefore was considered as another guiding principle within the design activity system.

v) Dimensions of puzzle solutions

During the puzzle design process a common consideration was the nature of the solution, especially considering the aims of supporting higher order thinking. Does the solution require a single answer or an understanding of a process, understanding of more than a single element? An example of this is reflected in the Diploidy puzzle where no clue with the complete answer exists. Rather the player is required to interact with the statue where they learn about what is required to solve it and in so doing develop a set of rules that might guide success. The puzzle offers an opportunity for players to apply their current understanding of the concept through the use of current student understanding (misconception). The problem serves not as an example with a single simple answer but rather the player discovers the rules as they interact with it.

A related facet of puzzle solutions is that the puzzle should be solved by application of understanding and not by a process of elimination or brute force. A challenge for the designer is to balance the amount of feedback the player receives information on their progress. The key for puzzle solutions is the emphasis on the quality of the interaction and the process, not just the answer, as the designer considers the *dimensions of the puzzle solution*.

3.6 Conclusion

The areas of tension and interest during the design process have been highlighted and may provide a useful framework for conceptualising aspects of elements applied. Emerging from the design process was: the organising function of the GAM, the need for awareness of personal ideologies, and the emergence of guiding principles in both story and puzzle development.

CHAPTER 4: GAME FORMATIVE EVALUATION

4.1 Introduction

Developmental research is an emerging paradigm within educational research that attempts to move beyond traditional descriptive outcomes and associated limitations of educational research which has been discussed by Reeves and Hedberg (2003) and van den Akker (2000) as lacking relevance with nothing meaningful to contribute.

In contrast to traditional approaches, developmental research eliminates the separation between design and evaluation, rather considering design as an opportunity for learning - a strategy for developing and refining theories (Edelson, 2002). Cobb, Confrey, diSessa, Lehrer and Schauble (2003) note that development research aims to develop theories about the learning and design process. It is both practical and theoretical in orientation and not simply about refining practice but addresses theoretical issues. “Design research should always have the dual goals of refining both theory and practice” (p19). Indeed considering the current division between practice and research in educational technology, Winn (2002) suggests the dual practical and theoretical orientations may help to eliminate the theory practice division evident in educational technology.

The developmental research process is described by van den Akker (2000) as cyclic process of analysis, design, evaluation and revision where successive prototypes come closer to the objectives. The process involves analysis, development of solution within theoretical framework, evaluation and testing, documentation and testing. This research process is considered by Cobb *et al.* (2003) to provide a testbed for innovation – for complex innovative task for which few guidelines exist (van den Akker, 2000). In the context of this study relatively few guidelines exist for the design of educational games.

Formative evaluation is considered to be important (Reeves and Hedberg, 2003) despite extensive resistance (Flagg, 1990). It is a key activity of developmental research which is used to guide the design, realize objectives and test design assumptions. Essential activities include expert reviews, user reviews and usability reviews (Reeves and Hedberg, 2003). The priority in formative evaluation is one of information richness (van den Akker, 2000) where it is important to include suggestions for improvement and not just locate the shortcomings. It is noted that formative evaluation ultimately contributes to the quality and improvement of the product.

In this chapter the formative evaluation of the game will be discussed. The evaluation employed the use of content and interactive design experts in addition to users to provide feedback. Each evaluation is organised around: story (narrative), puzzles and graphics.

4.2 Methods

As previously stated evaluation forms an important element of the design process. Both qualitative and quantitative methods are considered to have importance, and therefore an applied mixed methods approach was used to evaluate the game with structured expert reviews and limited user testing. Strategies employed were in-game discussions followed by a post-gameplay interview and questionnaire (see Appendix). The questionnaire makes use of a four point Likert scale and open-ended questions. This study makes use of expert and user reviewers. Due to the small numbers and emphasis on richness of response, a statistical analysis would be rendered meaningless.

4.2.1 Expert review

Expert reviews are the most frequently used formative evaluation strategy. An expert is defined as anyone with specialized knowledge that is relevant to the design of the learning system. There are several different kinds of experts, e.g. content or subject matter experts; instructional experts; graphic designers; teaching and training experts (Reeves and Hedberg 2003).

Two categories of expert were used for review: content experts (n = 3) and interactive design (n = 3) experts. A typical session lasted approximately 3 hours. A brief overview of the aims and objectives of the game were presented followed by a quick introduction to the game where evaluators could orientate themselves in the environment and introduce the story.

Content experts evaluated the i) information in the environment and ii) the strategies for success used in puzzles, whether or not erroneous ideas were being supported in solving the problems and iii) how the approach might be used in addressing student learning difficulties. The use of visuals in terms of information presentation, animation was probed in detail for potential to aid or hinder learning.

Interactive design experts evaluated the i) design of the environment in terms of navigation, visual and information presentation ii) puzzle interface design and finally and iii) story. The discussion of the story was woven into the analysis of puzzles and environment as these elements were also designed to support the story in addition to more overt examples such as animated sequences of game characters giving story points and miscellaneous notes and articles intended to add to the story. In addition a four point Likert scale and open ended questionnaire was used to evaluate the overall game environment. The information yielded from the discussions and open-ended questionnaire was transcribed and coded in *QSR* NVivo where themes and relationships were considered. Microsoft Excel and SPSS were used to create graphs.

4.2.2 User review

While expert reviews are considered important to the design process, user reviews are also regarded to be so. Users (n=3) were given tasks to i) find content and ii) use objects to perform tasks. The game was then played to completion to elicit opinions on the story and overall impressions. A cheat sheet was used where necessary to balance the need for finding info and experiencing the whole game in a limited time. In addition a four point Likert scale and open ended questionnaire was used to evaluate the overall game environment. The information from the discussions and open-ended questionnaire was transcribed and coded in *QSR* NVivo. *Microsoft* Excel and SPSS were used to create graphs.

4.3 Results and discussion

4.3.1 Post gameplay questionnaire

This component of the evaluation served to provide a quantitative overview of the reaction of reviewers to the game. These results are presented here to establish a context from which the interviews and in-depth discussion will add value later in the discussion as they probe specific features such as conceptual understanding and usability. Furthermore, the importance of motivational factors in addition to cognitive aspects of learning is highlighted here to draw attention to the motive of canvassing player opinions and preferences. Games represent an opportunity to facilitate features of both through play, and therefore an exploration of what players’ find motivating within the game environment is important to investigating the potential of the game as an educational tool.

Figures 4.1, 4.2 and 4.3 represent the responses of reviewers to the four point Likert scale and open ended questionnaire to questions about the story, puzzles and graphics. Considering the

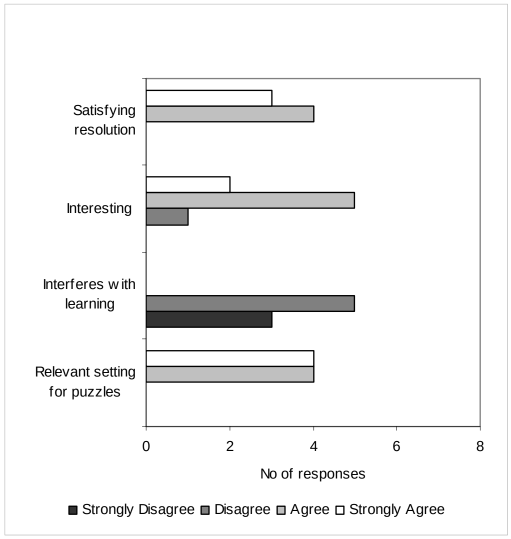


Figure 4.1. Reviewer responses to elements of the story. Considered to be satisfying, interesting and relevant. The issue of story and its relationship to games was noted. In spite of lack of interest in the function of stories in games the reviewer did find the game to be of educational merit (n=9).

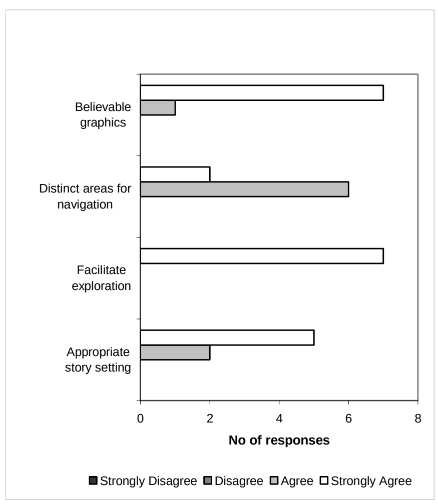


Figure 4.2. Figure showing reviewers responses to the game environment. Strong opinions on the believability of graphics and facility for exploration, and appropriate story setting. Less confidence expressed in distinct areas for navigation also this was unanimous in terms of agreement (n = 9).

importance of the story element to games and learning, key features of the story were probed and the results presented in Figure 1a. These features covered the story's appeal and relationship to the focused learning activities within the environment. Reviewers responded favourably, considering the story to be interesting, having a satisfying resolution and providing a relevant context for puzzles. The importance of the story, which is expanded upon later in this discussion, is its role as a context for the learning tasks or puzzles within the game environment.

In addition to the story, the graphics environment is key to how the player will experience the game and is therefore central in communicating elements of both the story and puzzles. Relevant features were assessed, namely the nature of the environment in terms of appearance, function and suitability to the story. The results (Figure 4.2) reveal agreement in terms of believability of the graphic environment and suitability supporting exploration and as an appropriate story setting.

The third key component of the game, the puzzles, represent the focused learning tasks within the game environment and the reviewers' opinion of the following attributes was sought to establish their perceived effectiveness in supporting the learning objectives of the game, namely: the relationships between puzzles, nature of their solutions, authenticity and the role of their visual design in facilitating learning. Figure 4.3 presents respondents opinions strongly supporting the tasks to be authentic in nature, challenging and interesting with clear relationships between them. Respondents were less confident but in general agreement that the designs supported goal formation with links between puzzles suggested through their design. Opinion over the following features differed slightly in scale yet were of a single opinion was apparent: potentially confusing nature due to similarities (disagree), varied in difficulty (agree), sufficient feedback (agree) and potentially frustrating nature of puzzles (disagree). Generally, the opinions of the reviewers endorsed the design decisions in developing the story, puzzles and graphics to support the learning objectives of the game.

Reviewers were given an opportunity to respond in their own words to a number of questions intended to elicit more detail about their opinions of the game environment. Reviewers wee asked to note what they liked most about the game. The results of this are presented in Figure 4.4. Responses that were most prevalent were the visual aesthetics, challenging learning tasks and information discovery. This highlights the importance players place on discovery and exploration and the learning tasks such activities support. Furthermore the importance of the visual aesthetics in bringing the environment to life is underscored. Opinion on what was disliked focused on issues around guidance and direction: some puzzle and story elements were unclear (Figure 4.5).

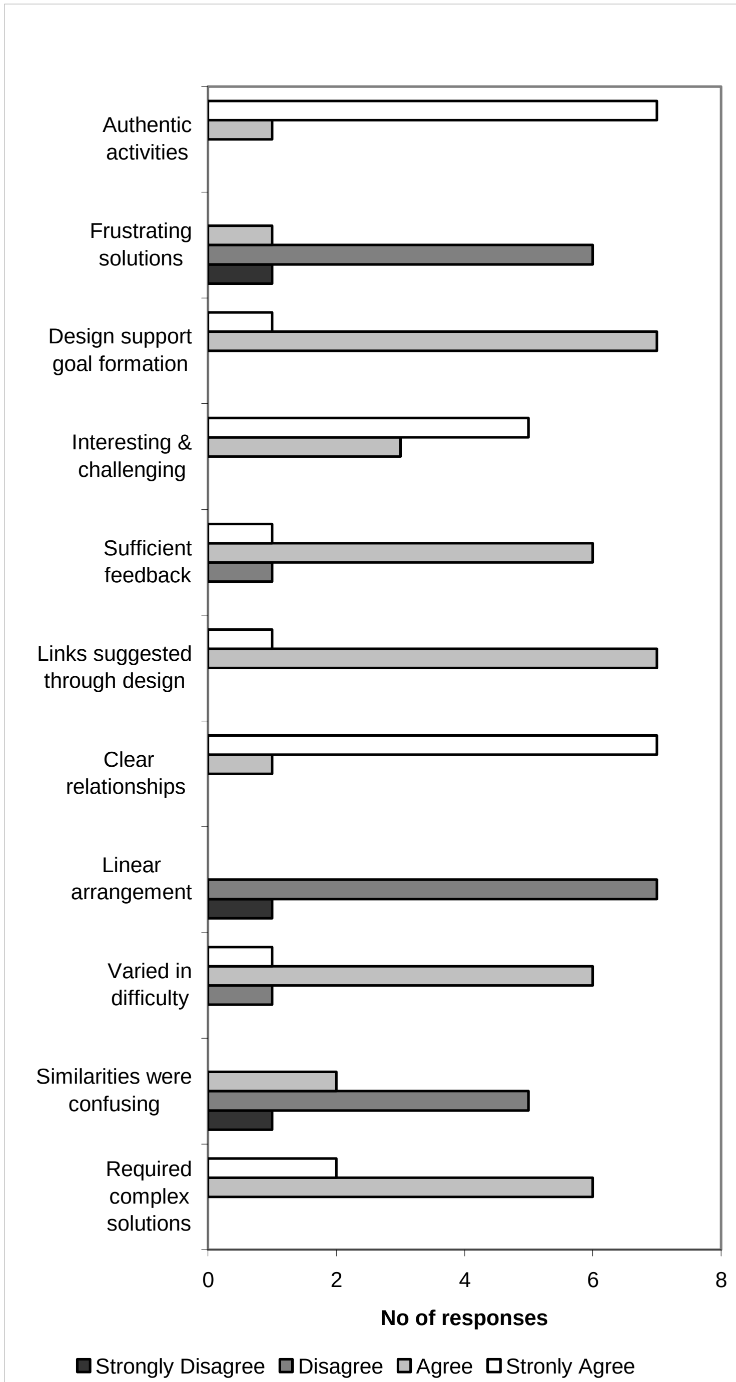


Figure 4.3. Reviewers opinions on the puzzles. Respondents felt strongly about the authentic nature of tasks with clear relationships and interesting and challenging problems. Less confident but in agreement, players agreed that designs supported goal formation, links suggested through design. Disagreement over linear problem arrangement. Opinion over the following more divided, although a single opinion was apparent: potentially confusing nature due to similarities (disagee), varied in difficulty (agree), sufficient feedback (agree) and potentially frustrating nature of puzzles (disagree) (n = 8).

With reference to the associated learning objectives, the presentation of science and scientific concepts in the game was assessed. The game was considered to represent an objective and balanced presentation of the field of science. In addition, and very important for learning, there were positive comments on the visual presentation of science concepts in terms of animation, graphics and illustrations which was created in style intending to reference the how these abstract concepts might be visualized in the real-world, and thus retain an element of authenticity (Figure 4.6).

In the light of the visual aesthetics being a feature of the game that players' found to their liking, opinions on what aspects of the graphics they specifically considered to be most important was probed. The results are presented in Figure 4.7. For players the detail, realism and immersion drew the most responses: all contribute to creating a rich and believable world in which players can explore and represents a powerful tool for designers with which to draw players into a learning environment. The elements discussed above are explored in further detail below.

Details of the story were investigated further, the results of which are presented in Figures 4.8 and 4.9. Player response to the perceived value of stories to games revealed key factors to be context and motivation (Figure 4.6). In addition, it was felt that there were indeed enough story fragments to follow the narrative although a number of respondents suggested the addition of more 'flashbacks' which were considered to be very effective in communicating plot points (Figure 4.9). This implies the desire for more communication of important dramatic events through drama and consequently video, i.e. show don't tell rather than reading about it through artefacts. This also highlights the importance for designers to achieve a balance between the presentation of content and how story elements are communicated in an effort to retain an element of drama.

As stated previously, the puzzles represents focused learning tasks designed to specifically address learning objectives. Player opinion on what they considered to be important elements of the puzzles is presented in Figure 4.8. Once again the visual elements drew the most responses, with other notable features to consider being: interesting outcomes, clear actions and feedback. This identifies what players value in puzzles as well as highlighting what features of the game puzzles were thought of as most important.,

Reviewer opinions on the relationship between puzzles and story was investigated and the results (Figure 4.11) highlight the value they place on integration between the two where it affords the game continuity and coherence. Case based scenarios, as suggested, represent a vehicle and

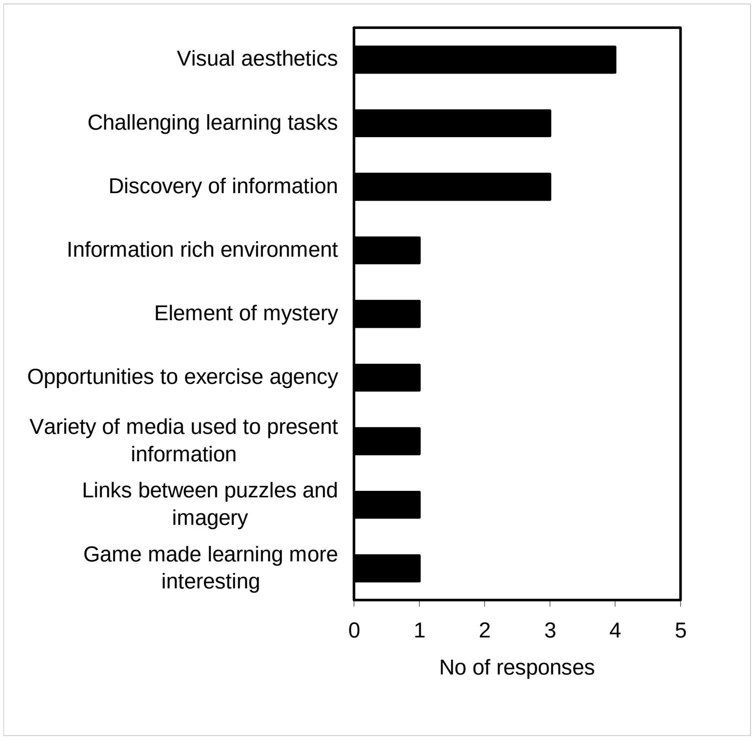


Figure 4.4. Reviewer views on what they liked most about the game. Visual aesthetics, challenging learning tasks and information discovery were the most popular aspects of the game (n = 8).

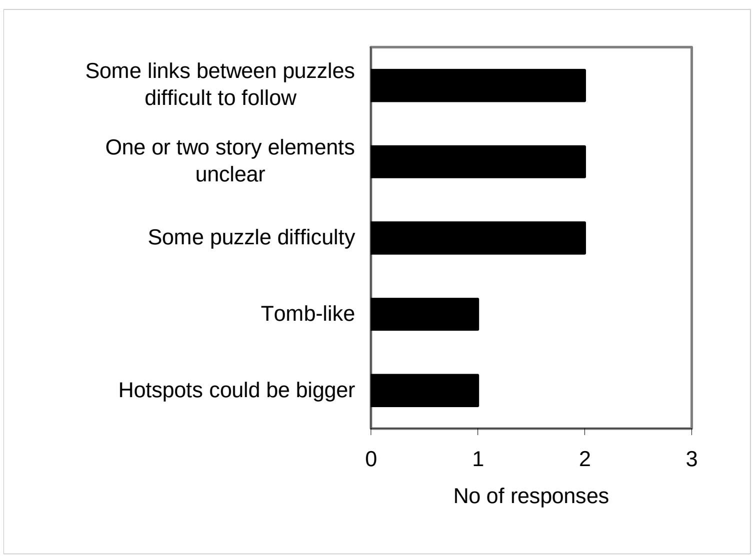


Figure 4.5. Reviewer opinions on their least liked aspects of the game which centered predominately around guidance and clarity of story and puzzles (n=8).

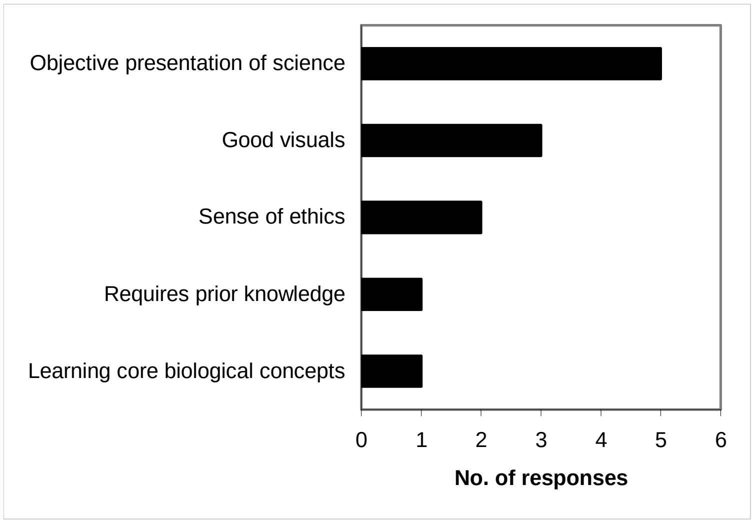


Figure 4.6. Reviewer opinions on the presentation of science in the game. It was considered to be an objective balanced presentation of the field of science. In addition, there were positive comments on the visual presentation of science concepts in terms of animation, graphics and illustrations (n=8).

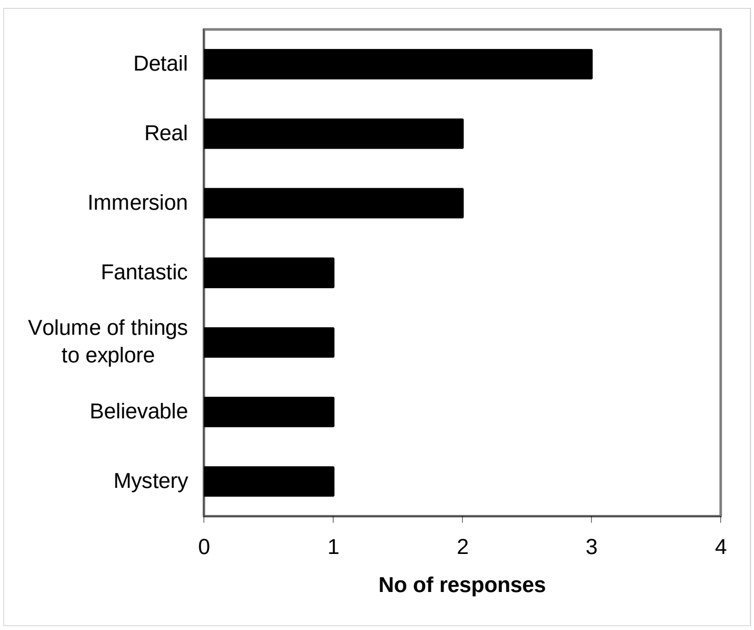


Figure 4.7. Reviewer opinions on what they liked about the graphics of the game. For players the detail, realism and immersion drew the most responses: all contribute to creating a rich and believable environment in which players can explore (n = 8).

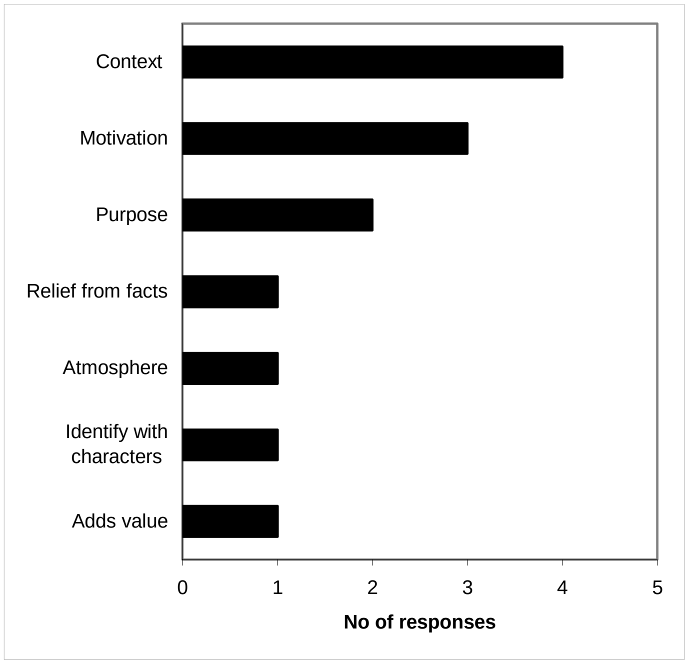


Figure 4.8. Reviewers responses to the perceived value of stories to games. Key factors are the context, motivation and purpose brought to the game: an environment within problems can be solved and information explored (n = 8).

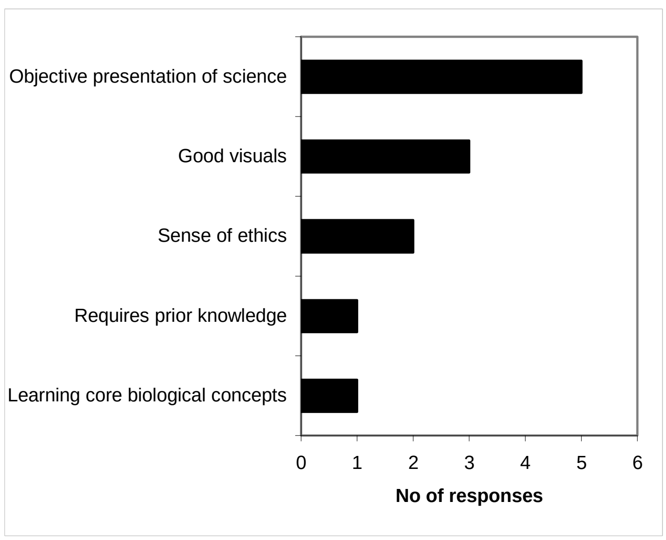


Figure 4.9. Reviewer opinions on the whether enough information as present. While all felt this was the case there were a number of suggestions for more flashbacks. This implies the desire for more communication of important dramatic events through drama and consequently video, i.e. show don't tell (n = 8).

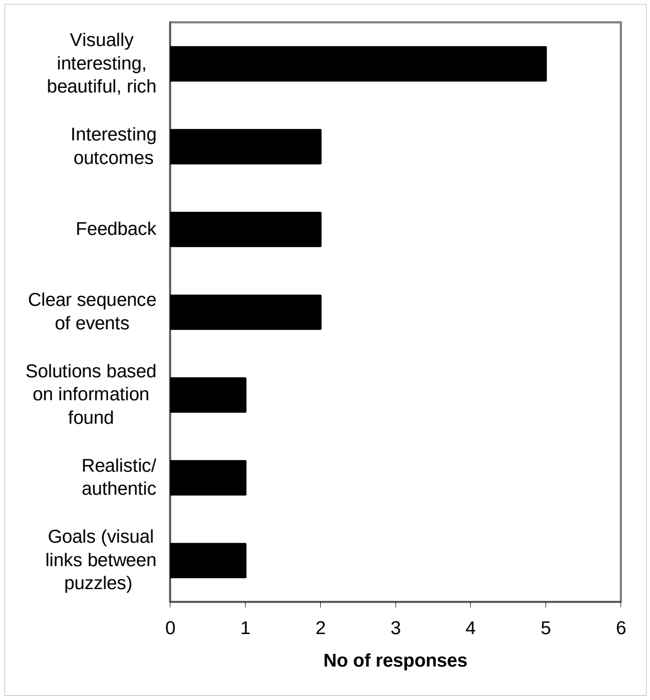


Figure 4.10. Reviewer opinions on what they most enjoyed about the puzzles. Once again the visual elements drew the most responses, other notable and important features to consider being: feedback, clear actions and feedback (n = 8).

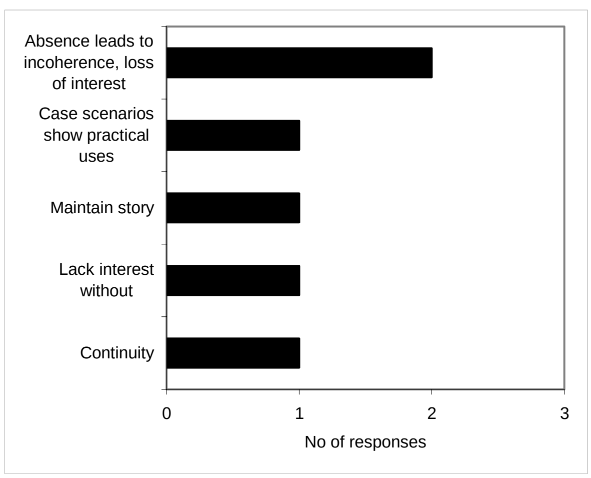


Figure 4.11. Reviewer opinions on the implications of story puzzle integration for the game: all responses hinted at an integrating function and reflects an element of the general role of stories in games. The case scenario aspect is also important as it represents a very useful teaching model (n = 8).

example of how puzzles (or learning tasks) can effectively be included within a story context.

To summarise, the responses of the reviewers validated the design of the game in terms of story, puzzles and graphics. Notable areas included: emphasis on realism and believability of graphics; effective presentation of concepts; a suggestion for more guidance in some puzzles; the importance of challenging activities which have clear actions, the need to balance the presentation of content with the needs of the narrative; importance of integrating of story and puzzle; and case-based scenarios and problem based learning being an effective reference for developing puzzles in the game environment. These elements will now be discussed in more detail as revealed based scenarios and problem based learning being an effective reference for developing puzzles in the game environment. These elements will now be discussed in more detail as revealed through discussion with the three groups of reviewers: content experts, design and interaction experts and users. A summary of the main points of the interviews is presented in Table 4.1.

4.3.2 Expert review: Content

Three experts in the field of genetics were consulted to assess the accuracy and appropriateness of the game in addressing genetics concepts. Each provided a slightly different perspective and ultimately useful insights for the development of the game, especially considering their teaching roles in addition to research interests. The aim of the review was to assess the accuracy of what was being presented and comment on the methods used to address the learning objectives of the game. The time that experts had available was limited and hence the review involved a guided walkthrough with comments, explanation and discussion. A typical session was two to three hours. The resulting discussion on their area of expertise relating to the game is organized around the themes of story, puzzles and graphics. The other reviews will be structured as such for consistency and facilitate comparison and summarising. In general, the reviewers were enthusiastic about the educational potential of the game to address the associated genetics learning objectives verifying the content in terms of accuracy, coverage and the application thereof within the game environment.

i) Graphics

The reviewers were unanimous in commending the visual representational tools to describe the many molecular and microscopic structures that function in the genetics domain in both puzzles and supporting information resources through the use of animation and illustration. Their potential for learning was enthusiastically acknowledged.

> Visuals help to understand the concept easier. Seeing it makes you remember … love the idea of animation.

Computers have the capability of creating dynamic symbolic representations of abstract concepts that are frequency missing in the mental models of novices (Kozma, 1991). Visual representations play an important role in communicating science concepts (Ametler and Pinto 2002) and successful teaching of science (Mathewson, 1999). Graphics are useful when representing phenomena that learners cannot directly observe or experience directly (Mathewson, 1999), making the abstract more concrete. Visual representations are preferred for displaying multiple relationships and processes that are difficult to describe with text alone (Patrick, Carter and Wiebe, 2005). Visual displays are powerful devices to support teaching and learning. Mayer and Moreno (2002) and Schnotz (2002) found that animation can promote learner understanding, showing consistency with cognitive theory of multimedia learning. The benefits of animation have been commented on by many authors (e.g. Schnotz, 2002), although it is important to note that one must take care in the use thereof. Animation facilitates a visual experience with the very abstract structures that students find difficult to conceptualise and this inaccessibility contributes to the learning difficulties associated with the subject domain. However, learners may not necessarily understand or realize what is being depicted. While care was taken to provide descriptions in e.g. the mitosis and meiosis puzzles, the reviewers did feel that the labelling of stages would be of benefit. Similarly, through the arrangement of chromosomes depicted at different levels of representation, the login puzzle provided opportunities for students to challenge their understanding of different representations of chromosomes. Once again this approach was enthusiastically commented on.

> Quite powerful. Seeing things in a visual manner.

The importance of understanding multiple representations is that failure to do so usually contributes to the difficulties in learning genetics and potential misconceptions. The approach was based on the literature to emphasise relationships and connections between different representations. Furthermore, the use of ‘authentic’ representations was used to depict many of the visual representations in the form of microscopy, diagrams and computer models to highlight

Table 4.1 Summary of key points from gameplay interview and discussion

	Content Experts	Interactive Design Experts	Users
Graphics	Good visual representational tools (animation) Support visualization of multiple representations of concepts Good visual linking between concept Suggest more labeling on graphics	Good graphics convey mood	Importance of realistic graphics to engaging learners Interesting and appealing representations (animation & illustrations)
Tasks & activities	Appropriate use of information for solving tasks Concepts not obvious but rather require meaningful learning Good problem based approach to learning design unites concepts & story elements	Contextualised authentic Suitably complex solutions Effective linking of puzzles to suggest relationships between concepts. Good use of hierarchies More guidance and feedback describing the system status Noted favourite puzzles have clear actions, e.g. being dna sequence/ objects and goal formation ..	Reflection on related puzzles Opportunities for linking concepts Feedback
Story	Interesting opportunities for learning Presentation of science and role of genetics is good Effectively show real world applications of genetics	Key ideas communicated. More detail may improve. Characters add interesting human dynamic More flashbacks	Motivation to find out more Need for additional guidance

the idea that these are representations and that each has limitations. Students are required to engage in multiple levels of thinking as they encounter concepts at different levels of organization - macro (organism) to micro (DNA, cells) to symbolic (genotype) (Bahar *et al.*, 1999; Johnstone and Mahmoud, 1980).

ii) Tasks and activities (puzzles)

Commentary on the type of activities and tasks that students would be engaged in were favourable and centered on authentic activities that extended across and provided crucial links between related concepts and subject domains. The activities in the game were considered to provide opportunities for engaging with genetics concepts in meaningful learning.

> … the merit (in this approach) is that concept is not obvious – different students take different times. It is very easy to use comparative tables, it becomes deep understanding when it but is not obvious.

A concern voiced by the author was the amount of information present within the environment which might be considered to be overbearing. This was refuted, however, with one reviewer stating it to be one of their favoured aspects. Rather, in the context of the game the use of the information in relevant tasks was noted a being of value, but the key was in the use of that information through puzzles.

> It’s not about the content but how to apply it.

Using this approach, students were challenged with concepts and how to solve the related problems through the appropriate use of that information. The similarity of this approach where a problem is presented and relevant information is used, i.e. problem based learning was noted by one reviewer in considering the use of diseases in the Genotype/ Phenotype and Punnet puzzles.

> But when you present something like this almost a case study type then you’re telling them what’s going wrong, this very much like problem based learning am I right? You give them a problem and then they work backwards knowing that all the basic facts are there … so I think it’s a very good way to ... because it’s not just a game on its own its doing it though a problem based learning way, I like that, I like that very much.

Indeed a problem based approach underlined much of the methodology of designing the puzzles. This was extended to unify different subject domains traditionally taught separately but each serving to highlight different facets of the role genetics plays in the physiology of living organisms i.e. protein synthesis. Authors (e.g. Longden, 1982; Radford *et al.*, 1982) have highlighted the need for this link in learning genetics. The Genotype Phenotype puzzle shows the path from genes to protein to facilitate an understanding of the biology of how genes function within the puzzle context which was commended.

> … relating the biology to the actual physiological processes is what students need to see they need to understand why we learn genetics not why we need to learn about Mendel …

> You've put together a lot of things ... not just teaching a section of genetics. It's the whole field of genetics and genetic technology and what it's used for … its really very good.

> If you can help them make the connections and you can show them why they're learning something I think they take to it better and your end result is better. And for me I see that is what your game is doing.

Through this approach the game environment and more specifically puzzles are seen to provide opportunities for players to construct links between concepts through activities based on relevant real world examples which included an element of fantasy in the form of a story. This fantasy aspect will be dealt with in next section.

iii) Story themes

The story element introduced themes addressed in the game which were considered to be of value in providing interesting opportunities for learning.

> ... remember that the concepts of genetics and field of genetics is not an easy one but you've captured something not in a book or set of notes … this will open up their minds to the fact that genetics is related to so many different things and the fact that it has clinical applications and where it came from … have an appreciation for science and research …"

The narrative elements of context and characters were tools to illustrate pertinent issues relating to the role of science and technology, where the complexities and complications of multiple points of view might be considered more engaging and interesting than sterile facts in isolation. Narrative thus serves to contextualise events and structure our experience in a meaningful way. Similarly, in a learning environment, narrative serves to both contextualise and structure the learning experience (Bruner, 1990).

To summarise, the main points raised by the experts centered on narrative opportunities for learning; the graphic presentation of concepts supporting multiple representation and linking different concepts, supporting an authentic approach to tasks that were suitably complex. The game in its current format was not without criticism, however, especially concerning a need for perhaps more guidance in areas such as labelling of animations in order to minimize the potential for confusion or mixed messages. This will be addressed later in the discussion.

4.3.3 Expert review: Design and Interaction

In addition to content experts, three experts in educational instructional design and usability were consulted to assess the educational and interactive design approach of the game in addressing genetics concepts. Once again, each provided a slightly different perspective and provided useful insights for the development of the game. The aim of the review was to assess the educational appropriateness, usability and design of the game and involved a directed walkthrough with comments, explanation and discussion. A typical session lasted approximately five hours.

In general, the reviewers were enthusiastic about the production quality and approach in addressing the learning objectives of the game. The experts verified the pedagogical approach focusing on the user interaction with the game, expanding in some detail on the comments in the questionnaire. The discussion is organized around the structure as the content expert review discussed above.

i) Graphics

The quality of the graphics was well received and fulfilled its function of communicating plot points.

> Oh I like the lighting the light is beautiful … ooh it's like something's happened there

ii) Tasks and activities (puzzles)

The learning tasks were considered suitably complex, contextualised and authentic in nature which went beyond simple facts but rather emphasized relationships between concepts.

> … were very strongly contextualized in terms of the material you're testing, material is presented you gather clues and puzzle directly related to what you're looking at, they are well situated.

In addition to supporting relationships between concepts, a key design goal had been that solutions to puzzles would generally involve more than just applying a simple 'answer' read on a page. Rather it would involve a process and application of understanding which was supported by the reviewers.

> Look beyond simple facts, look for relationships amongst facts … looking for relationships.

The hierarchical or metapuzzle structure used to arrange the puzzles was considered to be suitable for supporting players' discovery and relationships between concepts as defined in the learning objectives.

> They seemed to build in complexity from easier to more complex kinds of puzzles and those more complex ones required some understanding of previous puzzles in that.
>
> Hierarchical structure works well; build in complexity …

A common approach of adventure games has involved using puzzles with little capacity for thought or choice in their solution. The approach here, however, was to include puzzles of similar design in an attempt to offer players opportunities to make choices based on their understanding of a concepts as to which solution was appropriate.

However the need for guidance emerged especially in the design on some puzzles. Despite the desire for reflection players just didn't necessarily engage in the activity without prompting. One reviewer did acknowledge the exploratory nature of the game environment with the tension between feedback and problem solving evident. The issue of feedback will be discussed in the summary.

iii) Story

Accordingly, key story ideas were communicated i.e. break in etc, although there were suggestions for a little more detail in the way of video flashbacks. The use of characters also provided a favourable human dynamic as well as served valuable communication of plot points.

> … it makes it more personal cos now you have people involved it makes it more interesting cos now there a human dynamic ... and I think what they are saying is informative cos you're getting a background … you understand the content of the vial. The people definitely make it more.

In summary, the reviewers were positive in their response to the game. They did however suggest that a little more direction in some areas might alleviate potential for confusion, especially with reference to puzzles and their related feedback. This will be discussed in depth at the end of the review section.

4.3.4 User review

Users from the target group (young adults under 25 years of age) were used to elicit opinions, provide insight into their preferences and observe their actions within the game environment. The review involved a directed walkthrough with comments, explanation and discussion with a typical session lasting approximately five hours. In general, users reacted favourably to their game experience.

i) Graphics

For users the quality of graphics was established as being very important in communicating both story and puzzle elements which have an influence in providing the motivation to explore the virtual world. Comments such as the following demonstrate the effectiveness in communicating mood and context:

> I really like the feel of the old house … like you know the rooms where you've got all the information ... you can see its old and you get that sense of ... and its also a bit eerie at the beginning ... it's a bit more suspenseful …
>
> … I think it was very realistic it was very well done ..

The graphics served to bring previously inaccessible concepts and structures of genetics to life in interesting and appealing ways through animation and illustration facilitating players' opportunities to in some way experience the abstract concepts of genetics. Another factor which became evident from the discussion is that that this 'realism' and 'believability' of the game graphics affords the game experience a sense of credibility in the eyes of the player, and consequently a reason for engaging with the content and undertaking the learning activities. This is evident not only in the frequency of comments related to realism and believability but more specifically the manner in which the abstract structures and processes of genetics are depicted, validate the game as an activity worthy of investing attention.

> … it lends a sense of authenticity to it so it makes it seem more ... it's more real.
>
> Well it ... yeah … because you not just playing ... its not like silly thing somebody thought up there's more to it its more professional ... you feel like you're actually solving something you doing something its ... it's more interesting than just doing a biology thing ... makes it like playing a game but there is more to it than that so you don't feel like you're just playing a game

It would appear from the above quote that there is still an element of scepticism associated with games in an educational context. The realism and seriousness with which the game was developed would appear important in achieving buy in from players where serious issues were being addressed. There are many types of games and they vary in complexity. Prensky (2005) uses terms 'complex' and 'mini' to distinguish between different types of games and where the public's sole encounter is with the latter their perception of games is often one of triviality and the educational potential is not recognised. In addition, understanding of games differs across generations, and thus there are different views on what games might bring to the educational context varies.

ii) Tasks and activities (puzzles)

Common patterns of interaction emerged in the puzzle solving process through discussions with the players, e.g.

> I think I need to get the right sequence...
>
> So are you supposed to match?
>
> Now what am I going to do with that printout?

Initially, players attempted to assess what was required of them (Figure 4.12). This involved moving between a) identifying an action, i.e. matching activity, and b) testing for possible paths to success by probing the puzzle for feedback. In the case of objects that had been picked up, these also served to provoke goal forming activity. It is at this point where feedback is important as it shaped a players understanding of whether or not they are moving towards a solution. A player referring to information resources also forms part of this process which deals with the *what* and *how* of solving the puzzle. Players move between these activities until the correct path is found, and move on to d) by solving the puzzle. There is however, a step in between, c) where users establish *why* their strategy was successful in solving the puzzle. However not all users get to this point, and this is where a puzzle may not be entirely successful in addressing a misconception or support learning a concept. The implications for puzzle design is to ensure that players go through this process as without it a puzzle may be solved without understanding the concept.

This puzzle also retains elements of a conceptual change approach. The original conceptual change theory of Posner, Strike, Hewson and Gertzog (1982) provides an explanation of why conceptual change is so difficult. If a concept is entrenched and proven successful in use there is no dissatisfaction, and in the context of the game puzzle, no need to ask *why* was a solution successful. If no concept is available that the student thinks is intelligible and plausible then change is most unlikely. Students are frequently unable to understand new theory because their old concepts provide the interpretation schema for looking at new science concepts. The Diploidy

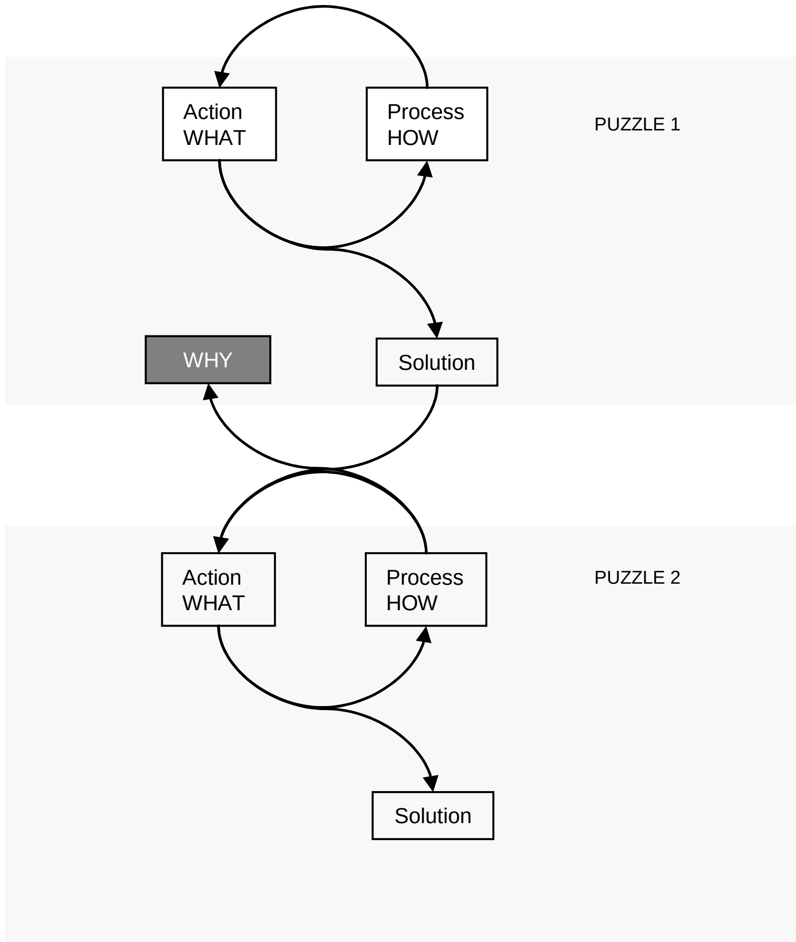


Figure 4.12. Player approach to solving puzzles is revealed in moving between establishing what and how is required to solve a puzzle. Upon solving the puzzle players to do not necessarily reflect on why their approach to solving the puzzle was successful. To address this associated puzzles make this step part of the process of what and how they need to do, i.e. the Ploidy Puzzle pair. However, this would benefit from an edition level of discourse i.e. collaboration with facilitator to probe and clarify the complexities of understanding biological concepts.

puzzle, and puzzle design process, was intended to challenge existing cognitive structures and misconceptions. Existing tools however fall short in being able to explore and interrogate the complexities inherent in conceptual understanding. It was only through articulation through discussion that the *why* element of the successful puzzle solution was brought to the learner's attention. Considering the complexity of the subject domain, some of these connections need to be made explicit through discussion with a facilitator or even fellow players. Students need to develop meaningful relationships with new conceptions in particular contexts with less emphasis on changing existing conceptions and more towards recognising the functional appropriateness of conceptions in particular contexts (Linder, 1993).

Upon solving the puzzle there is an additional step which relies on another puzzles, either a sibling puzzle, e.g. the paired puzzle approach employed to address ploidy (Diploidy and Haploidy Puzzles) or a parent or child puzzle that exists in a hierarchy, part of a metapuzzle structure (Kim and Pajitov, 2000) described in Chapter 3. This hierarchy is implemented to encourage reflection on the previous puzzle. Players were thus encouraged to reflect on other puzzles related to different concepts and consider the links between order to solve them and thus reflect on previous paths to success.

> … so then you know, once you've done one you know what you're looking for to do the next one.
>
> ... once you've done the first one, it kind of teaches you what to do for next, the first will be trial and error and then know for next one ... so it all flows, makes sense that way

In terms of design of tasks and activities, the approach of using similarly designed puzzles as objects of reflection and to connect concepts was validated as players demonstrated a reliance on thinking about the links between related puzzles to find a solution.

Furthermore, objects to be picked up also served as useful devices to prompt action, i.e. a page to be scanned. This proved more successful with objects players might encounter in everyday life and what was immediately recognizable what its function might be. A successful example of this was the task of amplifying, sequencing and scanning to obtain information on the vaccine, noted by a reviewer as a favourite due to it having a clear sequence of events. The individual steps thus gain meaning within the whole and therefore perhaps represents a more successful puzzle from a player motivation as well as usability point of view. There are multiple opportunities to think about the associated puzzle and so therefore reflect on the process and steps to come. This is contrasted with responses to the mitosis and meiosis gallery puzzles where there is no object which a player may have a functional understanding of, but is rather far more conceptual in nature where no clear links are visible. This suggests perhaps a taxonomy of puzzles so as to achieve the right balance.

iii) Story

The function of the story as context and motivation, hinted at in the questionnaire is explored further here. The story was considered to provide the linking context for the game activities.

> … you’re picking up story as you move … reading information is what makes it flow, and hearing snippets of conversations it does make it more interesting cos it links everything.
>
> What supported this context was the mystery associated with the story. They noted that until the conclusion they weren’t quite sure what exactly was happening, the curiosity of what was taking place leading them to explore further. But I thought it was very well thought out and I liked the that it was quite mysterious until the end I didn’t know quite exactly
>
> It become mysterious in that you want to find out even more I really enjoyed the end
>
> While one can infuse an element of mystery there is a fine line between encouraging exploration and confusing a player leading to frustration and even boredom. It was noted that at times more

Guidance could possibly have been included. While having an element of complexity, some story details, in fact, were not communicated or resolved intentionally.

> … you’re left it very open .. it leaves a whole lot of questions to answer for themselves or come up with there own answers so that is good.

Players were thus empowered to fill in their own details and draw their own conclusions. The potential for discussion and sharing of opinions is evident here.

In summary, the target user group found the game to be motivating and something worth engaging with as a learning tool.

4.4 Reflecting on playing activity

A number of key issues were highlighted in the different reviews that were undertaken and are summarised in the previous section. To facilitate a discussion of these issues in a holistic manner the player activity will be analyzed though the lens of an activity system, in the same was the designer activity was discussed. Drawing on these themes a general system of activity was developed representing a synthesis of the players’ activity in all aspects of the game experience, as illustrated in Figure 4.13. Comments from interviews were analysed and used for populating the system to highlight key areas for discussion. From this system a number of guiding principles emerged which might to further guide the design of educational games and develop an awareness of the many factors that contribute to an educational game.

Puzzles

During the game review process of a number of contradictions emerged within the activity system especially in terms of designer decisions and what actually occurs when playing the game. A recurring theme was that of direction and guidance which is reflected in the relationships between a number of the components within the system.

i) Puzzle progress & feedback

An internal contradiction exists within the player activity system between the puzzle design (tool) and the rule (puzzle solution based on understanding). For players, the puzzle interfaces as well as story and information resources served as mediating artefacts in the system where the object was learning genetics concepts with the game. The puzzles represented opportunities for players to engage with focused learning tasks that would challenge their current understanding of biological concepts. Among the rules of the system was that progress in the game was based on players' understanding of concepts demonstrated by the successful completion of specific puzzles. In an effort to respect these rules and avoid feedback that would facilitate the completion of puzzles without an understanding of the relevant concept, the amount of feedback and direction was generally controlled.

Players found a need for more guidance in the solution of some puzzles, e.g. the mitosis and meiosis sequence puzzles as links were not apparent to some, although the compressed testing time was acknowledged. Reflections on the nature of persistence in puzzle states and feedback which enabled players to solve puzzles by a process of elimination were noted and discussed in detail during the gameplay process. There are number of additional factors which add value to this discussion. Comments from reviewers, especially the content experts, have noted the need to avoid confusion amongst learners about what they were learning, an important point of consideration and noted that were diverse levels of prior knowledge in potential learners (subject). What emerges as important for feedback is *supporting the player in assessing their progress* in solving the puzzles. This monitoring may be considered a metacognitive tool.

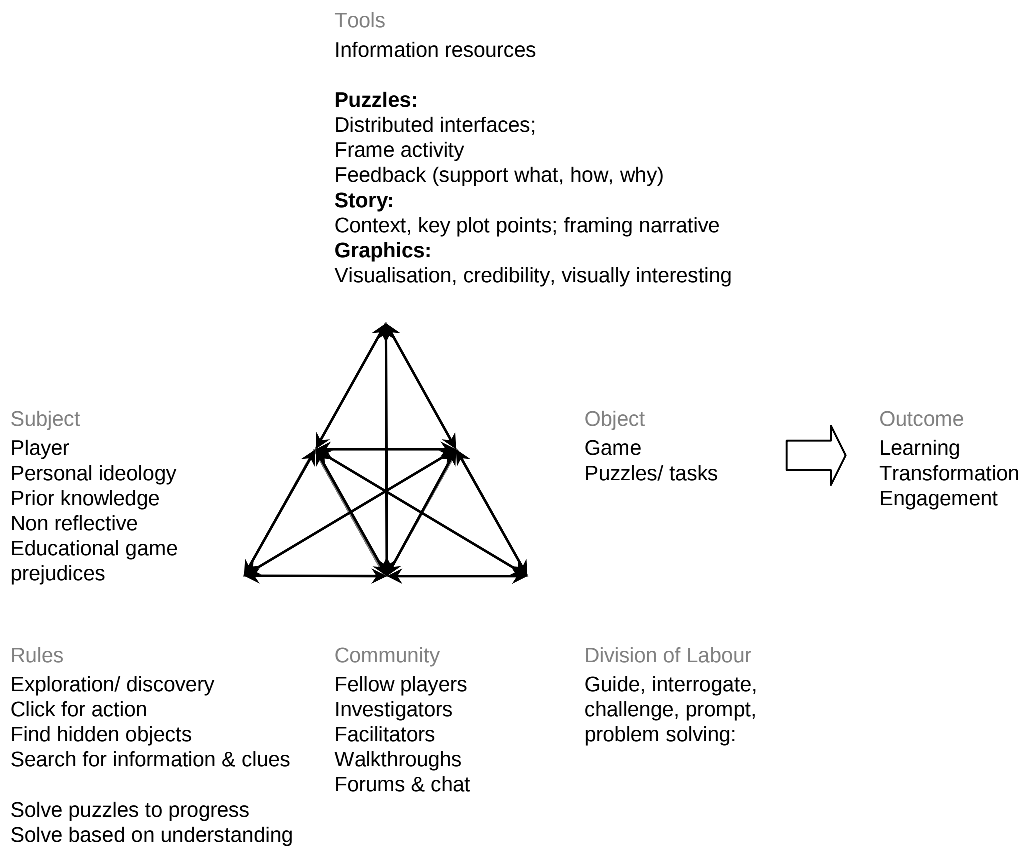


Figure 4.13. Player activity system derived from reviewer gameplay interviews.

As discussed previously the need for feedback when engaging with complex interfaces results in a competing focus on learning to use the tool and learning the concept. From a theoretical perspective the player is focusing on operations rather than activities with the system. Puzzles and systems may usually be considered successful where using the interface exists at the level of unconscious operations. However where there is a breakdown, these operations revert to the level of actions (Kaptelinen, 1996) and cognitive effort is required to finding out how the system works which is in contradiction to the player focussing on using their understanding will solve the problem. Despite their being an element of discovery in an adventure game, discovering these rules should not be at the expense of learning the concept. Roth and Lee (2007) however state that this has positive implications for learning which will be discussed in the following section.

ii) Social metacognitive support

Another contradiction within the system also exists between the rule (puzzle solution based on understanding) and the subject not necessarily reflecting on what they have done to solve the puzzle. The premise is that the design of the puzzle is such that solving it is an indication of understanding it. However, as revealed during the review process and conceptualised earlier in the discussion, a critical step in the puzzle solving process emerged as understanding why a particular strategy for a solution was successful. As demonstrated in the discussion about the Diploidy and Haploidy puzzles in the previous section, this metacognitive step does not necessarily occur without prompting. The review process where the author acted as facilitator therefore demonstrated the value of a collaborative approach to playing where puzzles served as a context for discussion of concepts introducing an additional level of scaffolding. The puzzle represents an opportunity for a discussion of: *what* action is required, how might the solution be achieved, and *why* is this method successful. The discussion between reviewer and player around the Diploidy puzzle interface and solution revealed an interesting opportunity to interrogate a player’s understanding while still in the context of the game environment. It seizes upon opportunities not afforded by current game tools to question, probe and clarify a player’s understanding and their thoughts about the concepts in question and in so doing introduces a collaborative element into the system. The contradictions described here may both provide a stimulus for learning. In terms of a breakdown where operations revert to actions Koschmann, Kuutti and Hickman (1998) suggest these to be important precursors to inquiry and learning.

In addition, a number of contemporary game researchers (Gee, 2003; Shaffer *et al.*, 2004; Squire, 2003b; Squire and Barab, 2004; Steinkuehler, 2004, 2006) have alluded to the value of extended game communities as providing rich social learning opportunities. Shaffer *et al*. (2004) consider the social practices afforded by games where communities are formed by game players. Communities organise meaningful learning experiences. Games immerse players in the epistemic frame of a particular community – the activities values and ways of seeing. Activities around current game communities include the creation of walkthroughs, hints and puzzles solutions. This social problem solving activity is also evident in another situated learning environment namely the Jasper Woodbury series (Cognition and Technology Group at Vanderbilt, 1992). The game thus becomes the focal point of a community and provides opportunities to discuss and reflect on the key issues and puzzles.

To conclude, the above stated contradictions may potentially undermine some of the learning features of puzzles. These might however be potentially alleviated by rather including an element of collaborative problem solving and employing the puzzle context as a place for discussion and interrogation, provoking players to ask deep and complex questions. The element of *social metacognitive support* is thus introduced.

iii) Framing the activity

The review process afforded the opportunity to assess the types of activity (and ultimately puzzles) that players responded to well. This suggests a guiding principle of the *framing the activity* of the puzzle and relates closely to puzzle relationships, the difference being that this refers to puzzle solving process as having a beginning middle and end. In comparing the Sequencing puzzle with the Diploidy Puzzle it was noted the Sequencing puzzle had a clear sequence of actions and that the activity they were engaging in had clear relationships through a number of distributed interfaces, whereas the Diploidy Puzzle was more conceptual with players engaging with a single complex interface. Although the Diploidy puzzle did form part of a puzzle hierarchy it remained more conceptual and not as process orientated as the Vaccine sequencing puzzle. In a similar manner, Laurel (1991) has suggested 'designing the action' as an approach to engaging human computer interaction. With reference to theatre, she suggests that the designer should consider the flow of activity in accomplishing a goal, rather than individual actions, something the Vaccine sample identification puzzle did well. Engaging players in these learning tasks is key and therefore represents an important need to motivate players to participate in interesting and meaningful problems. These puzzles are effectively linked using process orientated tasks.

To summarise, designers should develop a clear ‘mini-narrative’ for the puzzle design process. In addition this also introduces the element of a classification of puzzles in terms of multiple distributed puzzle interfaces as opposed of single complex entities requiring complex interactions, numerous different states and feedback.

Furthermore a clear organising activity was evident in the case of the Vaccine samples puzzle. While a context was implemented for other puzzles it was most successful here perhaps due to the flow of the action as well as comparative simplicity of the associated interfaces. In terms of Activity Theory, an activity is realized through concrete actions, which are directed toward goals. In this context the activity is represented by the overall act of discovering the location of the vaccine where the actions are directed towards specific goals e.g. sequencing or probing which occur at a single puzzle interface. In other words the goal at each of these interfaces is evidently clear. Moreover as Roth and Lee (2007) state the results of actions become part of the resources available in later stages of the activity for subsequent actions. Each puzzle relationship becomes a resource either in terms of an object in the game or a reflective tool with which to solve other problems.

Narrative discovery

A contradition was evident in the relationship between the narrative comprehension component of the system and player preferences. Many requested a little more story in terms of traditional presentation, i.e. video flashbacks or cutscenes. It is perhaps a matter of the way the story is presented as there was much in terms of artefacts and implied notes but nothing to strongly tie in together. As a result of time constraints less attention was given to these sequences but considering player feedback, more should be included, possibly prioritising video for all the key plot points to ensure their communication in an engaging as well as prominent way. Players responded favourably to the overarching linear background narrative with local elements of interaction employed. This framing narrative was suggested by Lindley (1995). The design process intended to create a story which would be complex and interesting. The complexity of the story, however, should not overwhelm the player and detract from the game as a learning experience. Where the story twists dominate the game, its value as a learning tool is rendered impotent, i.e. cognitive load is too great. Considering the story’s organising and structural role in shaping the experience it is perhaps wise to err on the side of simplicity so as not to compete with the demands of conceptual understanding.

4.5 Conclusion

The formative evaluation process served to provide information to inform future design decisions. Generally the responses to the game were favourable and validated the design approach to addressing genetics misconceptions by focusing on the multiple representations, highlighting the relationships between concepts and unifying different subject domains. Additional elements were introduced though story themes and reflected a problem based learning approach. The importance of believability and realism to players communicating a sense of credibility was also noted. The game thus brought a level of enjoyment to a subject domain usually associated with an element of fear for students and in so doing addressed motivational factors in addition to the cognitive.

There were a number of calls for additional guidance in some areas which reflects an opportunity to add value to the learning experience. Many of the reviewers acknowledged that given sufficient time would have found the necessary links but considering the compressed nature of the testing session, there wasn't time for total freedom of exploration.

The puzzle solving process and discussion did however reveal interesting relationships and tensions with a proposed application of collaborative problem solving which was visualized using an activity system. Considering the calls for more guidance, the puzzle serves as a space where a facilitator might discuss and probe players' understanding while providing sufficient support to ensure that one set of misconceptions are not replaced by another.

CHAPTER 5: CONCLUSION

5.1 Introduction

The two previous chapters served to describe the initial design, development and formative evaluation of the game tool. This final chapter serves to summarise and synthesise the principal concepts from previous chapters and reflection on the use of development research (design experiments) and Activity Theory as an organising framework.

5.2 Initial design and development stage

The initial phase of design and development revealed the following:

5.2.1 GAM and its application

The GAM was a useful and effective tool in structuring the design activities. Games are particularly complex systems to create and there is an inherent possibility for a loss of focus. The GAM represented an organizing feature in the process to ensure that the initial objectives of the project remained at the forefront of priorities in the development process.

5.2.2 The designer activity system

There were a number of lessons learnt during the initial design phase. This phase was characterized by the activity of the designer making decisions based on the literature and his own insight. An activity system was used to visualise the system and the components therein. Key ideas were discussed around the following themes: design specification, personal ideology, framing narrative and ‘game rules’ which included story-puzzle integration, puzzle relationships and dimensions of puzzle solutions.

5.3 Formative evaluation

The formative evaluation revealed the following:

5.3.1 Expert and User Reviews

Experts (content and interactive design) and users (young adults under 25) evaluated the game on appropriate use of story, graphics and puzzles in addressing misconceptions. Generally, all reviewers responded favourably with the quality of the production and approach commended. Key points of interest were the visual presentation of the abstract concepts that characterise the domain of genetics; the realism and believability of the graphics and the use of story themes to frame problems. The need for more direction was a common theme that emerged. A number of reviewers felt that more guidance was in order although they did state that the test period was compressed without time to explore and play fully. It does raise the topic, explored in the player activity system, of balancing the quality of puzzle feedback with solving the puzzle based on an understanding of the concept in question. This does suggest the usefulness for a facilitator where the game and puzzle supports discussion and collaboration.

5.3.2 The player activity system

The key components that emerged from the evaluation were discussed in the context of an activity system, namely: puzzle feedback, solving puzzles and narrative comprehension. The amount of puzzle feedback versus solving the puzzle by application of what has been learnt was a distinct tension.

5.4 Reflecting on Development research and Activity Theory

The unique opportunity afforded by the process of development research is the potential to refine and improve on a design intervention - an opportunity for learning where theories can be developed and refined (Edelson, 2002). The formative evaluation has provided a rich insight into attitudes of a range of reviewers to *Food for Thought* in identifying strengths and weaknesses of the intervention. This ongoing process would benefit from an opportunity to undertake a large scale summative evaluation incorporating reviewer suggestions and lessons learnt in order to quantitatively assess learning in detail and what benefits, in terms of learning outcomes, games bring to learners in a real world context advocated by the research paradigm.

This investigation employed activity theory as an organising framework with which to analyse the two areas of activity that formed the core of the project: the designer and the player. Previous investigations have used activity theory as a lens for analysing student participation (Barab, Evans and Baek, 2004). This approach proved beneficial in terms of the development research process as the activity systems provided a consistent point of reference from which to compare and implement revisions to the system. Here the relationship between the decisions of the designer and the activity of player was clear and provided a coherent framework for comprehending the required changes and how they would be integrated into the existing process.

Activity theory with its associated interrelationships and contradictions provides an appropriate tool for analysing the game environment considering its complexity, interrelated goals and relationships between components which are also a feature of games. Games are complex systems and particularly difficult to conceptualise. Furthermore, activity theory acknowledges the importance of affective and not just cognitive factors associated with learning (Leont'ev, 1978), a key element of this approach to the use of games.

Considering the dialectic nature of activity systems, contradictions are evident on a number of levels. When made conscious they become a driving force for change within systems (Roth and Lee, 2007). In so doing, contradictions between the player and designer activity systems served to modify elements of the designer system thereby refining the practice and serving to effectively support the developmental research agenda. Similarly the contradictions in the player activity system served to highlight shortcomings of initial design approach which are resolved by considering social metacognitive tools to support the player and are incorporated into the modified designer activity system. This serves to highlight the importance of this approach to design where the design cannot occur in isolation but rather in the context of an iterative design research process.

5.4 Revised designer activity system

The details of contradictions between the two activity systems have been described in the previous chapters. The designer activity system revealed a number of 'game rules' which guided the design process, namely puzzle relationships, integration of puzzle and story, narrative discovery, and dimensions of puzzle solutions which provided tentative rules to adhere to in the puzzle design process. From the game evaluation additional rules were noted to add value to this process: player progress feedback, collaborative puzzle solving and framing of the activities. Many of the contradictions within the player system emerged as a tension between rules defined in the design process. These have been incorporated into the revised designer activity system presented in Figure 5.1.

The final rule of 'framing the activity' refers to always considering a puzzle in terms of its context, and design a clear flow of actions unified into an activity so that a player is less focused on using the system but rather on learning. A concept for a classification of puzzles in terms of interface complexity (multiple states versus distributed simple interfaces) is also noted. Here the flow of the activity provides the motivation and organising structure, i.e. four relatively simple points of interaction (interfaces) involved in the Vaccine sequencing puzzle linked by a clear flow

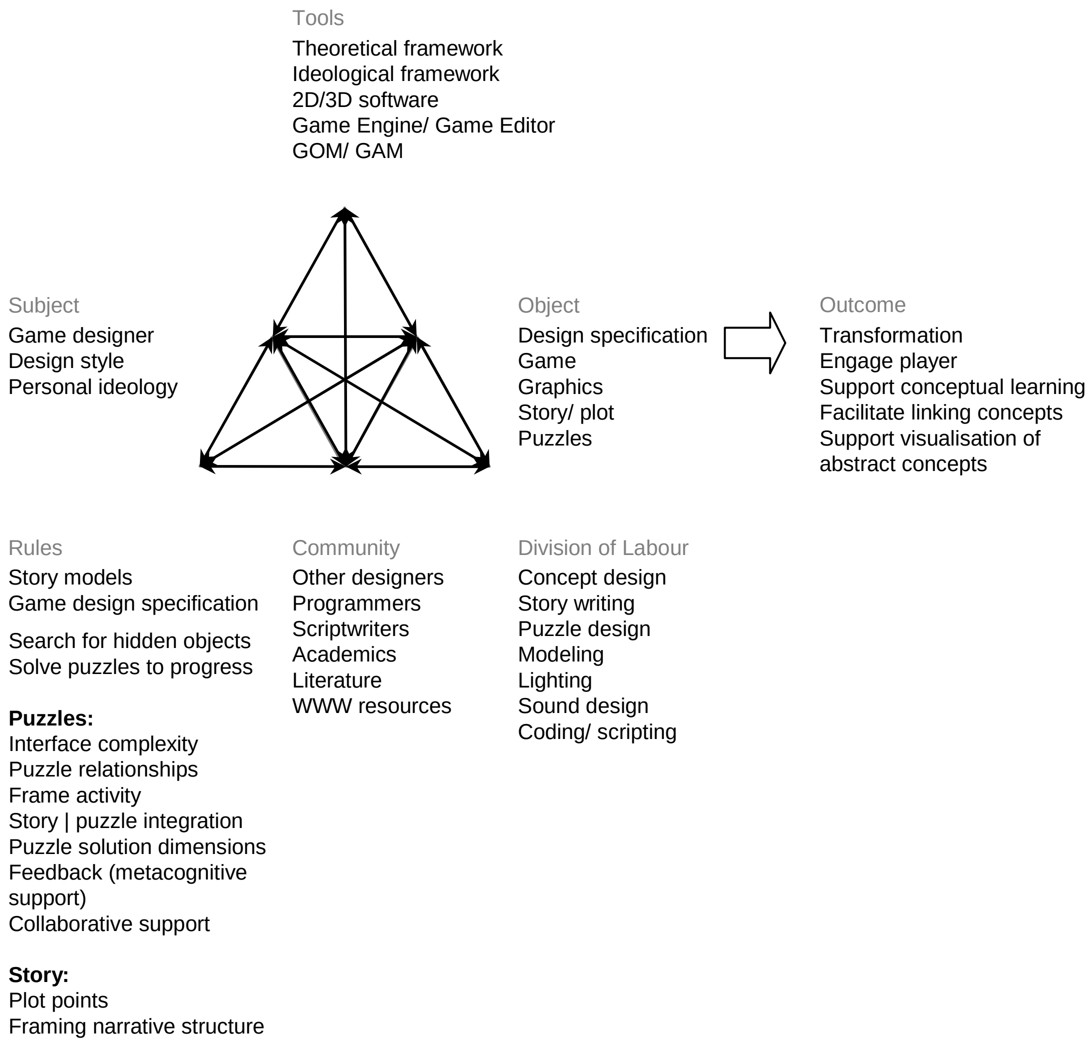


Figure 5.1. Revised designer activity system based on lessons learnt from contradictions between designer and player activity systems.

of action. This is contrasted with the complexity of the mitosis sequence puzzle where feedback is critical to understanding how to use it. However, too much and the puzzle is solved by a process of elimination. In this case, collaboration becomes a useful tool to preserving the learning integrity of the puzzle, taking advantage of social constructivist practices and avoiding player frustration.

Considering the developmental research approach of this investigation these additional elements will be used to modify the activity system of the designer as additional ‘game rules’ which would serve to guide the designer through the next iterative phase of development presented. In terms of the dialectical nature of activity theory these features may be considered in terms of ‘mutually exclusive category pairs (Roth and Lee, 2007).

5.4 Conclusion

This development does by no means represent the only approach to using of games in education. Ironically it was probably the designer who probably learnt the most about genetics during the game development process. Indeed, alternative methods include allowing learners to design their own games (Kafai, 1994, 2006; Rieber, Davis, Matzko and Grant, 2001). Whatever the approach, this will contribute to enriching our understanding of the complex yet promising world of learning with games. Improving technology and development of emerging narratives hold exciting future for meaningful and complex interactive story with the player exhibiting more control and engaging in richer interactions.

An interesting element of the development process was software limitations. Working within an educational context meant that the latest tools may be beyond cost and need given the number of features. For example the outdated lighting model of 3D Max required the designer to find innovative ways to develop engaging and believable images for the game through the use of multiple layers of images. However, for designers the tools for creating worlds are expanding. More open source tools are becoming available, so access to development tools should not be seen as a limitation for games. Open source tools empower even educational institutions to harness what not so long ago was a huge investment in cost and resources. Games should no longer exist within the realm of the vast budgets but rather there is now a viable opportunity to employ games as an engaging method of learning.

Technology affords the creation of rich complex worlds but the technology should not define the way games are used in education. The latest cutting edge innovation is replaced ever more quickly so the principle remains to base the design on sound learning theory. The main focus in this investigation has been to identify a set of principles to guide the creation of meaningful learning experiences that support both cognitive and motivational factors.

REFERENCES

Adams, E. (2003). The Construction of Ludic Space. Paper presented at: DiGRA.

Allchin, D. (2000). Mending Mendelism. *American Biology Teacher* **62**, 633-639.

Amory, A. (2001). Building an Educational Adventure Game: Theory, Design, and Lessons. *Journal of Interactive Learning Research* **12**, 245-259.

Amory, A. (2003). Another Country: Virtual Learning Spaces. Paper presented at: Proceedings of ED-MEDIA (Honolulu, Hawaii, USA).

Amory, A., Naicker, K., Vincent, J., and Adams, C. (1999). The use of Computer Games as an Educational Tool: 1. Identification of Appropriate Game Types and Game Elements. British *Journal of Educational Technology* **30**, 311-322.

Amory, A., and Seagram, R. (2003). Educational game models: conceptualisation and evaluation. *South African Journal of Higher Education* **17**, 206-217.

Atkins, M.J. (1993). Theories of learning and multimedia applications: an overview. *Research Papers in Education* **8**, 251-271.

Bahar, M., Johnstone, A.H., and Hansell, M.H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education* **33**, 84-86.

Banet, E., and Ayuso, E. (2000). Teaching genetics at secondary school: a strategy for teaching about the location of inheritance information. *Science Education* **84**, 313-351.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., and Tuzun, H. (2005). Making Learning Fun: Quest Atlantis, A Game Without Guns. *Educational Technology, Research and Development* **53**, 86-107.

Barab, S.A., Evans, M.A., and Baek, E.-O. (2004). Activity theory as a lens for characterizing the participatory unit. In Handbook of Research in Educational Communications and Technology, D.H. Jonassen, ed. (Washington, D.C., Association for Educational Communications and Technology), pp. 199-214.

Barrass, R. (1984). Some misconceptions and misunderstandings perpetuated by teachers and textbooks of biology. *Journal of Biological Education* **18**, 201-206.

Barrows, H.S. (1986). A taxonomy of problem-based learning methods. *Medical Education* **20**, 481-486.

Bednar, A.K., Duffy, T.M., and Perry, J.D. (1992). Theory into practice: How do we link? *In* Constructivism and the technology of instruction: A conversation, T.M. Duffy, and D.H. Jonassen, eds. (Hillsdale, NJ, Erlbaum).

Bliss, J. (1995). Piaget and after: The case of learning science. *Studies in Science Education* **25**, 139-172.

Bransford, J., Sherwood, R., and Hasselbring, T. (1988). The Video Revolution and its Effects on Development: Some Initial Thoughts. *In* Constructivism in the Computer Age, G. Forman, and P.B. Pufall, eds. (Mahwah, New Jersey, Lawrence Erlbaum Associates, Inc.), pp. 173-201.

Brown, J.S., Collins, A., and Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher* **18**, 32-42.

Bruckman, A.S. (1998). Community Support for Constructionist Learning. *The Journal of Collaborative Computing* **7**, 47-86.

Bruner, J. (1986). Actual Minds, Possible Worlds: Possible Worlds (Cambridge and London, Harvard University Press).

Bruner, J. (1990). Acts of Meaning (Cambridge, MA, Harvard University Press).

Buckingham, D., and Scanlon, M. (2000). That's edutainment. Paper presented at: International forum of researchers on young people and the media (Sydney, Australia).

Buckley, B.C. (2000). Interactive multimedia and model-based learning in biology. *International Journal of Science Education* **22**, 895- 935.
Calahan, S. (1996). Storytelling through Lighting: A Computer Graphics Perspective. Siggraph '96 Course #30.
Carson, D. (2000a). Environmental Storytelling: Creating Immersive 3D Worlds Using Lessons from the Theme Park Industry. http://www.gamasutra.com/features/20000301/carson_01.htm (Gamasutra: Art and Science of Making Games).
Carson, D. (2000b). Environmental Storytelling: Part II: Bringing Theme Park Environment Design Techniques to the Virtual World. http://www.gamasutra.com/features/20000405/carson_01.htm (Gamasutra: Art and Science of Making Games).
Carson, D. (2004). Environmental Storytelling: Part III: Lesson learned in the Virtual World. http://www.gamasutra.com/features/20040920/carson_01.htm (Gamasutra: Art and Science of Making Games).
Cheek, D.W. (1992). Thinking Constructively About Science, Technology, and Society Education (SUNY Press).
Cho, H., Kahle, J.B., and Nordland, F.H. (1985). An Investigation of High School Biology Textbooks as Sources of Misconceptions and Difficulties in Genetics and Some Suggestions for Teaching Genetics. *Science Education* **69**, 707-719.
Clark, R.E. (1991). When researchers swim upstream: reflections on an unpopular argument about learning from media. *Educational Technology* ***February 1991**, 34-40.
Clark, R.E. (1994). Media will never influence learning. *Educational Technology, Research and Development* **42**, 21-29.
Cobb, P. (1994). Where is the Mind? Constructivist and Sociocultural Perspectives on Mathematical Development. *Educational Researcher* **23**, 13-20.
Cobb, P., Confrey, J., diSessa, A., Lehrer, R., and Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher* **32**, 9-13.
Cognition and Technology Group at Vanderbilt (1992). The Jasper Experiment: An Exploration of Issues in Learning and Instructional Design. *Educational Technology, Research and Development* **40**, 65-80.
Cognition and Technology Group at Vanderbilt (1993). Anchored Instruction and Situated Cognition Revisited. *Educational Technology* **33**, 52-70.
Cole, P. (1992). Constructivism Revisited: A Search for Common Ground. *Educational Technology* **32**, 27-34.
Cooper, P.A. (1993). Paradigm Shifts in Designed Instruction: From Behaviorism to Cognitivism to Constructivism. *Educational Technology* **33**, 12-18.
Cordova, D.I., and Lepper, M.R. (1996). Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contextualizion, Personalization, and Choice. *Journal of Educational Psychology* **88**, 715-730.
Costikyan, G. (2000). Where Stories End and Games Begin. In Game Developer, pp. 44-53.
Csikszentmihalyi, M. (1979). The Concept of Flow. In Play and Learning, B. Sutton-Smith, ed. (John Wiley & Sons Inc), pp. 257-294.
Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience (New York, Harper & Row).
Cuban, L. (2001). Oversold and underused: Computers in the classroom. (Cambridge, MA, Harvard University Press).
de Castell, S., and Jenson, J. (2003). Serious Play. *Journal of Curriculum Studies* **35**, 649-665.
Dede, C. (1992). The Future of Multimedia: Bridging to Virtual Worlds. *Educational Technology* **32**, 54-60.

Dempsey, J., Lucassen, B., Gilley, W., and Rasmussen, K. (1993). Since Malone's Theory of Intrinsically Motivating Instruction: What's the Score in the Gaming Literature? *Journal of Educational Technology Systems* **22**, 173-183.

Dempsey, J.V., Lucassen, B.A., Haynes, L.L., and Casey, M.S. (1996). Instructional Applications of Computer Games. Paper presented at: AERA (New York, NY).

Dickey, M.D. (2005). Three-dimensional virtual worlds and distance learning: two case studies of Active Worlds as a medium for distance education. *British Journal of Educational Technology* **36**, 439-451.

Duffy, T.M., and Cunningham, D. (1996). Constructivism: Implications for the Design and Delivery of Instruction. *In* Handbook of Research for Educational Communications and Technology, D.H. Jonassen, ed. (Washington, DC, Association for Educational Communications and Technology), pp. 170-198.

Duffy, T.M., and Jonassen, D.H. (1991). Constructivism: New Implications for Instructional Technology. *Educational Technology* **31**, 7-12.

Duit, R., and Treagust, D.F. (1998). Learning in science – From behaviourism towards social constructivism and beyond. In International handbook of science education, K. Tobin, and B. Fraser, eds. (Dordrecht, The Netherlands, Kluwer Academic Publishers), pp. 3-26.

Duit, R., and Treagust, D.F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. International Journal of Science Education *25*, 671-688.

Edelson, D.C. (2002). Design Research: What We Learn When We Engage in Design. *Journal of the Learning Sciences* **11**, 105-121.

Feldman, C. (2005). Mimesis: Where play and narrative meet. *Cognitive Development* **20**, 503-513.

Flagg, B.N. (1990). Formative Evaluation for Educational Technologies (Hillsdale, NJ Lawrence Erlbaum Associates).

Fortugno, N., and Zimmerman, E. (2005). Learning to Play to Learn. Lessons in Educational Game Design.

Fosnot, C.T. (1996). Constructivism: A Psychological Theory of Learning. *In* Constructivism: theory, perspectives and practice, C.T. Fosnot, ed. (New York, Teachers College Press).

Gagne, R., Briggs, L., and Wager, W. (1988). Principles of Instruction Design (New York, Holt, Reinhard, & Winston).

Gagne, R.M., and Dick, W. (1983). Instructional Psychology. *Annual Review of Psychology* **34**, 261-295.

Gee, J.P. (2003). What video games have to teach us about learning and literacy. (New York, Palgrave Macmillan).

Gil-Perez, D., and Carrascosa, J. (1990). What to do about Science "Misconceptions". *Science Education* **74**, 531-540.

Grabinger, R.S. (1996). Rich environments for active learning. In Handbook of Research for Educational Communications and Technology, D. Jonassen, ed. (New York., Macmillan Library Reference,USA), pp. 665-719.

Gredler, M.E. (1992). Learning and instruction: Theory into Practice (Upper Saddle River, NJ, Merrill/ Prentice Hall).

Gredler, M.E. (1996). Educational games and simulations: A technology in search of a (research) paradigm. In Handbook of Research for Educational Communications and Technology, D.H. Jonassen, ed. (Washington, DC, Association for Educational Communications and Technology), pp. 521-540.

Gredler, M.E. (2004a). Games and simulations and their relationships to learning, 2nd Edition edn (Washington, DC, Association for Educational Communications and Technology).

Gredler, M.E. (2004b). Games and simulations and their relationships to learning. *In* Handbook of Research in Educational Communications and Technology, D.H. Jonassen, ed.

(Washington, DC, Association for Educational Communications and Technology), pp. 571-581.

Greening, T. (1998). Building the Constructivist Toolbox. *Educational Technology* **38**, 23-35.

Greeno, J.G., and Moore, J.L. (1993). Situativity and Symbols: Response to Vera and Simon. *Cognitive Science* **17**, 49-59.

Griffiths, A.J.F., and Mayer-Smith, J. (2000). Understanding Genetics: Strategies for Teachers and Learners in Universities and High Schools.

Halldén, O. (1999). Conceptual Change and Contextualization. *In* New Perspectives on Conceptual Change, W. Schnotz, S. Vosniadou, and M. Carreteo, eds. (Amsterdam Pergamon), pp. 53-65.

Heim, W. (1991). What is a Recessive Allele? *American Biology Teacher* **53**, 94-97.

Herrington, J., and Oliver, R. (2000). An Instructional Design Framework for Authentic Learning Environments. *Educational Technology Research and Development* **48**, 23-48.

Jenkins, H. (2002). Game Design as Narrative Architecture. *In* First Person, P. Harrington, and N. Frup-Waldrop, eds. (Cambridge, MA, MIT Press), pp. 118-130.

Jenkins, H. (2005). Games, the New Lively Art. In Handbook of Computer Game Studies, J. Raessens, and J. Goldstein, eds. (Cambridge, MA, The MIT Press), pp. 175-189.

Johnstone, A.H., and Mahmoud, N.A. (1980). Isolating topics of high perceived difficulty in school biology. *Journal of Biological Education* **14**, 163-166.

Jonassen, D.H. (1991). Objectivism versus Constructivism: Do we need a new Philosophical Paradigm? *Educational Technology, Research and Development* **39**, 5-14.

Jonassen, D.H. (1999). Designing Constructivist Learning Environments. *In* Instructional-design theories and models: A new paradigm of instructional theory, C.M. Reigeluth, ed. (Mahwah, New Jersey, Lawrence Earlbaum Associates), pp. 215-239.

Jonassen, D.H., and Hernandez-Serrano, J. (2002). Case-Based Reasoning and Instructional Design: Using Stories to Support Problem Solving. *Educational Technology, Research and Development* **50**, 65-77.

Jonassen, D.H., and Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology, Research and Development* **47**, 61-79.

Juul, J. (2002). Introduction to Game Time. *In* First Person: New Media as Story, Performance, and Game, N. Wardrip-Fruin, and P. Harrigan, eds. (Cambridge, Massachusetts, MIT Press), pp. 131-142.

Kafai, Y.B. (1994). Minds in play: computer design as a context for children's learning (Hillsdale, New Jersey, Lawrence Erlbaum Associates, Inc.).

Kafai, Y.B. (2006). Playing and Making Games for Learning. *Games and Culture* **1**, 36-40.

Kaptelinen, V. (1996). Activity theory: Implications for human-computer interface. In Context and consciousness, B. Nardi, ed. (Cambridge, MA., MIT Press), pp. 103-116.

Kiili, K. (2005). Digital Game-Based Learning: Towards an Experiential Gaming Model. *Internet and Higher Education* **8**, 13-24.

Kim, S., and Pajitov, A. (2000). The art of puzzle game design. Paper presented at: Game Developers Conference (San Jose).

Kindfield, A. (1991). Confusing chromosome number and structure: a common student error. *Journal of Biological Education* **25**, 193-200.

Kindfield, A.C.H. (1994). Understanding a basic biological process: expert and novice models of meiosis. *Science Education* **78**, 255-283.

King, G., and Krzywinska, T. (2002). Computer Games/ Cinema/ Interfaces. Paper presented at: Computer Games and Digital Cultures Conference (Tampere, Tampere University Press).

Kirkley, S.E., and Kirkley, J.R. (2005). Creating Next Generation Blended Learning Environments Using Mixed Reality, Video Games and Simulations. *TechTrends* **49**, 42-53;89.

Klevjer, R. (2002). In Defense of Cutscenes. Proceedings of Computer Games and Digital Cultures Conference.
Knippels, M.C.P.J., Warlo, A.J., and Boersma, K.T. (2005). Design criteria for learning and teaching genetics. *Journal of Biological Education* **39**, 108-112.
Koschmann, T., Kuutti, K., and Hickman, L. (1998). The concept of breakdown in Heidegger, Leont'ev, and Dewey and its implications for education. *Mind, Culture, and Activity* **5**, 25-41.
Koschmann, T.D., Myers, A.C., Feltovich, P.J., and Barrows, H.S. (1994). Using technology to assist in realizing effective learning and instruction: A principled approach to the use of computers in collaborative learning. *The Journal of the Learning Sciences* **3**, 227-264.
Kozma, R.B. (1991). Learning with Media. *Review of Educational Research* **61**, 179-211.
Kurshan, B. (1991). Creating the global classroom for the 21st century. *Educational Technology* **31**, 47 - 50.
Land, S.M., and Jonassen, D.H. (2000). Introduction. In Theoretical Foundations of Learning Environments, D.H. Jonassen, and S.M. Land, eds. (Mahwah, New Jersey, Lawrence Erlbaum & Associates).
Laurel, B. (1991). Computers as Theatre (Reading, Mass, Addison-Wesley Publishing Company).
Lave, J., and Wenger, E. (2000). Situated Learning: Legitimate Peripheral Participation (New York, NY, Cambridge University Press).
Lawson, A.E., Alkhoury, S., Benford, R., Clark, B.R., and Falconer, K.A. (2000). What Kinds of Scientific Concepts Exist? Concept Construction and Intellectual Development in College Biology. *Journal of Research in Science Teaching* **37**, 996-1018.
Lazarowitz, R., and Penso, S. (1992). High school students' difficulties in learning biology concepts. *Journal of Biological Education* **26**, 215-223.
Lebow, D. (1993). Constructivist Values for Instructional Systems Design: Five Principles Toward a New Mindset. *Educational Technology, Research and Development* **41**, 4-16.
Leont'ev, A.N. (1978). Activity, consciousness and personality. (Englewood Cliffs, NJ, Prentice Hall).
Lepper, M.R., and Malone, T.W. (1987). Intrinsic Motivation and Instructional Effectiveness in Computer-Based Education. In Aptitude, learning, and instruction, III: Conative and affective process analysis, R.E. Snow, and M.J. Farr, eds. (Hillsdale, NJ, Lawrence Erlbaum Associates), pp. 255-286.
Lewis, J., and Kattmann, U. (2004). Traits, genes, particles and information: re-visiting students' understandings of genetics. *International Journal of Science Education* **26**, 95-206.
Lewis, J., Leach, J., and Wood-Robinson, C. (2000a). All in the genes? - young people's understanding of the nature of genes. *Journal of Biological Education* **34**, 74-709.
Lewis, J., Leach, J., and Wood-Robinson, C. (2000b). Chromosomes: the missing link - young people's understanding of mitosis, meiosis, and fertilization. *Journal of Biological Education* **34**, 189-199.
Lewis, J., and Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance - do students see any relationship? *International Journal of Science Education* **22**, 177-195.
Linder, C.J. (1993). A challenge to conceptual change. *Science Education* **77**, 293-300.
Lindley, C.A. (2005). Story and Narrative Structures in Computer Games. In Developing Interactive Narrative Content, Bushoff, and Brnhild, eds. (Munich, High Text).
Longden, B. (1982). Genetics - are there inherent learning difficulties? *Journal of Biological Education* **16**, 135-140.
Malacinski, G.M., and Zell, P.W. (1996). Manipulating the "Invisible". *The American Biology Teacher* **58**, 428-432.
Malliet, S., and de Meyer, G. (2005). The History of the Video Game. In Handbook of Computer Game Studies, J. Raessens, and J. Goldstein, eds. (Cambridge, MA, MIT Press), pp. 23-46.

Mallon, B., and Webb, B. (2005). Stand Up and Take Your Place: Identifying Narrative Elements in Narrative Adventure and Role-Play Games. *ACM Computers in Entertainment* **3**.

Malone, T.W. (1981a). Toward a Theory of Intrinsically Motivating Instruction. *Cognitive Science* **4**, 333-369.

Malone, T.W. (1981b). What Makes Computer Games Fun? *Byte*, 258-277.

Malone, T.W., and Lepper, M.R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. Aptitude, learning, and instruction III: Conative and affective process analysis. *In*, R.E. Snow, and M.J. Farr, eds. (Hillsdale, NJ, Lawrence Erlbaum Associates), pp. 223-253.

Mathewson, J.H. (1999). Visual-Spatial Thinking: An Aspect of Science Overlooked by Educators. *Science Education* **83**, 33-54.

Matthews, M.R. (2000). Appraising Constructivism in Science and Mathematics Education. *In* Constructivism in Education, D.C. Phillips, ed. (Chicago, Illinios, University of Chicago Press), pp. 161-192.

Mayer, R.E., and Moreno, R. (2002). Animation as an Aid to Multimedia Learning. *Educational Psychology Review* **14**, 87-99.

McAllister, K.S. (2004). Game work: Language, power, and computer game culture (Alabama, University of Alabama Press).

McKee, R. (1999). Story. Substance, structure, style and the principles of screenwriting. (London, Methuen).

Merrill, D.M. (1991). Constructivism and Instructional Design. *Educational Technology* **31**, 45-52.

Millerson, G. (1991). The technique of lighting for television and film, 3rd edn (Boston, Focal Press).

Murray, J.H. (1997). Hamlet on the Holodeck (New York, The Free Press).

Neitzel, B. (2005). Narrativity in Computer Games. In Handbook of Computer Game Studies, J. Raessens, and J. Goldstein, eds. (Cambridge, MA, The MIT Press), pp. 227-245.

Newman, J. (2002). In Search of the Videogame Player. *New Media and Society* **4**, 405-422.

Nussbaum, J., and Novick, S. (1982). Alternative Frameworks: Conceptual Conflict and Accommodation: Toward a Principaled Teaching Strategy. *Instructional Science* **11**, 183-200.

Oliver, R., and Herrington, J. (2003). Exploring Technology-Mediated Learning from a Pedagogical Perspective. *Journal of Interactive Learning Environments* **11**, 111-126.

Papert, S. (1998). Does easy do it? Children, Games, and Learning. *Game Developer* **5**, 88.

Pashley, M. (1994). A-level students: their problems with gene and allele. *Journal of Biological Education* **28**, 121-126.

Patrick, M.D., Carter, G., and Wiebe, E.N. (2005). Visual Representations of DNA Replication: Middle Grades Students' Perceptions and Interpretations. *Journal of Science Education and Technology* **14**, 353-365.

Perkins, D. (1991). Technology Meets Constructivism: Do They Make a Marriage? *Educational Technology* **31**, 18-23.

Phillips, D.C. (1995). The Good, the Bad, and the Ugly: The Many Faces of Constructivism. *Educational Researcher* **24**, 5-12.

Piaget, J. (1972). Principles of Genetic Epistemology (London, Routledge & Kegan Paul).

Pintrich, P.R., Marx, R.W., and Boyle, R.A. (1993). Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change. *Review of Educational Research* **63**, 167-199.

Polkinghorne, D.E. (1988). Narrative Knowing and the Human Sciences (New York, State University of New York Press).

Posner, G.J., Strike, K.A., Hewson, P.W., and Gertzog, W.A. (1982). Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education* **66**, 211-227.
Prensky, M. (2005). In Digital Games for Education, Complexity Matters. *Educational Technology* **45**, 22-28.
Quinn, C.N. (1994). Designing educational computer games. In Designing for Change in Teaching and Learning, K. Beattie, C. McNaught, and S. Wills, eds. (Elsevier Science), pp. 45-57.
Quinn, C.N. (2005). Engaging Learning: Designing e-Learning Simulation Games.
Radford, A., and Bird-Stewart, J.A. (1982). Teaching genetics in schools. *Journal of Biological Education* **16**, 177-180.
Randel, J.M., Morris, B.A., Wetzel, C.D., and Whitehill, B.V. (1992). The Effectiveness of Games for Educational Purposes: A Review of Recent Research. *Simulation and Gaming* **23**, 261-276.
Reeves, T.C. (1995). A Model of the Effective Dimensions of Interactive Learning. Paper presented at: Computer-Assisted Education and Training in Developing Countries (Muckleneuk, Pretoria).
Reeves, T.C. (2000). Enhancing the Worth of Instructional Technology Research through “Design Experiments” and Other Development Research Strategies. Paper presented at: Annual Meeting of the American Educational Research Association (New Orleans, LA, USA.).
Reeves, T.C., and Hedberg, J.G. (2003). Interactive Learning Systems Evaluation (Englewood Cliffs, NJ, Educational Technology Publications).
Rieber, L.P. (1996). Seriously Considering Play: Designing Interactive Learning Environments based on the blending of Microworlds, Simulations and Games. *Educational Technology, Research and Development* **44**, 43-58.
Rieber, L.P. (2001). Designing learning environments that excite serious play. Paper presented at: Australasian Society for Computers in Learning in Tertiary Education (Melbourne, Australia.).
Rieber, L.P., Davis, J., Matzko, M., and Grant, M. (2001). Children as Multimedia Critics: Middle School Students' Motivation for and Critical Analysis of Educational Computer Games Designed by Other Children. Paper presented at: AERA 2001 (Seattle).
Rieber, L.P., and Matzko, M.J. (2001). Serious design of serious play in physics. *Educational Technology* **41**, 14-24.
Rieber, L.P., Smith, L., and Noah, D. (1998). The Value of Serious Play. *Educational Technology* **38**, 29-37.
Rogoff, B., and Lave, J. (1992). Everyday cognition: Its Development in Social Context.
Rollings, A., and Adams, E. (2003). Andrew Rollings and Ernest Adams on Game Design (New Riders Publishing).
Roth, W., and Lee, Y. (2007). “Vygotsky’s Neglected Legacy”: Cultural-Historical Activity Theory. *Review of Educational Research* **77**, 186-232.
Ryan, M.L. (2002). Beyond Myth and Metaphor: Narrative in Digital Media. *Poetics Today* **23**, 581-608.
Salen, K., and Zimmerman, E. (2004). Rules of play: game design fundamentals (Cambridge, MA, MIT Press).
Salen, K., and Zimmerman, E. (2005). Game Design and Meaningful Play. *In* Handbook of Computer Game Studies, J. Raessens, and J. Goldstein, eds.
Savery, J.R., and Duffy, T.M. (1995). Problem Based Learning: An Instructional Model and Its Constructivist Framework. *Educational Technology* **35**, 31-38.
Schank, R. (1994). Goal-Based Scenarios: A Radical Look at Education. *Journal of the Learning Sciences* **3**, 429-453.

Schank, R.C. (1990). Tell me a story: a new look at real and artificial memory. (New York, Scribner).
Schnotz, W. (2002). Towards an Integrated View of Learning From Text and Visual Displays. *Educational Psychology Review* **14**, 101-120.
Shaffer, D.W., Squire, K., Halverson, R., and Gee, J.P. (2004). Video games and the future of learning. Report published by the Academic ADL Co-Lab, Madison, Wisconsin; Retrieved October 12, 2005 from http://wwwacademiccolaborg/resources/gappspaper1pdf.
Skinner, B.F. (1953). Science and Human Behaviour (New York, Macmillan).
Skinner, B.F. (1968). The Science of Human Behavior. In Twenty-five years at RCA laboratories 1942-1967 (Princeton, New Jersey, RCA Laboratories), pp. 92-102.
Squire, K. (2003a). Design Principles of Next-Generation Digital Gaming for Education. *Educational Technology* **43**, 17-23.
Squire, K. (2003b). Video Games in Education. *International Journal of Intelligent Simulations and Gaming* **2**.
Squire, K., and Barab, S. (2004). Replaying History: Engaging Urban Underserved Students in Learning World History Through Computer Simulation Games. Paper presented at: Proceedings of the 2004 International Conference of the Learning Sciences http://labwebeducationwiscedu/room130/PDFs/squire01pdf (Mahwah, New Jersey, Erlbaum).
Steinkuehler, C. (2004). Learning in massively multiplayer online games. Paper presented at: Sixth International Conference of the Learning Sciences (Mahwah, NJ. Erlbaum).
Steinkuehler, C. (2006). The Mangle of Play. *Games and Culture* **1**, 199-213.
Stewart, J., Hafner, B., and Dale, M. (1990). Students' Alternate Views of Meiosis. *American Biology Teacher* **52**, 228-232.
Sutton-Smith, B. (1979). Play and learning. (John Wiley & Sons, Inc.).
Sutton-Smith, B. (1997). The ambiguity of play. (Cambridge, MA, Harvard University Press).
Tobin, K., and Tippins, D. (1993). Constructivism as a Referent for Teaching and Learning. *In* The practice of constructivism in science education, K. Tobin, ed. (Washington, DC, AAAS Press.), pp. 3-21.
Tolman, R.R. (1982). Difficulties in Genetics Problem Solving. *American Biology Teacher* **44**, 525-527.
Tsui, C.-Y., and Treagust, D.F. (2004). Motivational Aspects of Learning Genetics with Interactive Multimedia. *American Biology Teacher* **66**, 277 - 285.
Turkle, S., and Papert, S. (1991). Epistemological Pluralism and the Revaluation of the Concrete. In Constructionism, I. Harel, and S. Papert, eds. (Norwood, NJ, Ablex Publishing Corporation), pp. 161-192.
van den Akker, J. (2000). Principles and Methods of Development Research. *In* Design Approaches and Tools in Education and Training, J. van den Akker, R.M. Branch, K. Gustafson, N. Nieveen, and T. Plomp, eds. (Kluwer), pp. 1-14.
Venville, G.J., and Treagust, D.F. (1998). Exploring Conceptual Change in Genetics Using a Multidimensional Interpretive Framework. *Journal of Research in Science Teaching* **35**, 1031-1055.
von Glasersfeld, E. (1989). Cognition, Construction of Knowledge, and Teaching. *Synthese* **80**, 121-140.
von Glasersfeld, E. (1996). Introduction: Aspects of Constructivism. *In* Constructivism: theory, perspectives and practice, C.T. Fosnot, ed. (New York, Teachers College Press), pp. 3-7.
Vygotsky, L. (1978). Mind in Society: The Development of Higher Psychological Processes (Cambridge, Massachusetts, Harvard University Press).
Wertsch, J., Minick, N., and Arns, F. (1984). The Creation of Context in Joint Problem-Solving *In* Everyday cognition: Its development in social context, B. Rogoff, and J. Lave, eds. (Cambridge, MA, Harvard University Press).

Wilson, B.G. (1995). Metaphors for Instruction: Why We Talk About Learning Environments. *Educational Technology* **35**, 25-30.

Wilson, B.G., and Myers, K.M. (2000). Situated Cognition in Theoretical and Practical Context. *In* Theoretical Foundations of Learning Environments, D.H. Jonassen, and S.M. Land, eds. (Mahwah, New Jersey, Lawrence Erlbaum & Associates).

Winn, W. (2002). Current Trends in Educational Technology Research: The Study of Learning Environments. *Educational Psychology Review* **14**, 331-351.

Wood-Robinson, C., Lewis, J., and Leach, J. (2000). Young people's understanding of the nature of genetic information in the cells of organisms. *Journal of Biological Education* **35**, 29-36.

APPENDIX

Food for Thought Game Evaluation

Story overview

The story is set amidst the concern over biotechnology and genetically modified organisms. A number of outbreaks of viral infections have decimated a number of small communities which are now under quarantine. Dr Khanyi Msizi leads a small private research facility in the development of a vaccine in partnership with the Department of Health. The project was recently re-assigned to be administered by a former colleague giving rise to an element of tension. Her belief is that the vaccine should be made freely available. She has realized the control is not the key, that sometimes there are things beyond one's control.

In contrast a former colleague, Xolani Mhlongu, believes the vaccines have a lucrative potential. He advocates control yet his argument is apparently about safety. He is bitter though and his motives are primarily driven by a desire to humiliate Dr Msizi as a result of what occurred just over a decade previously.

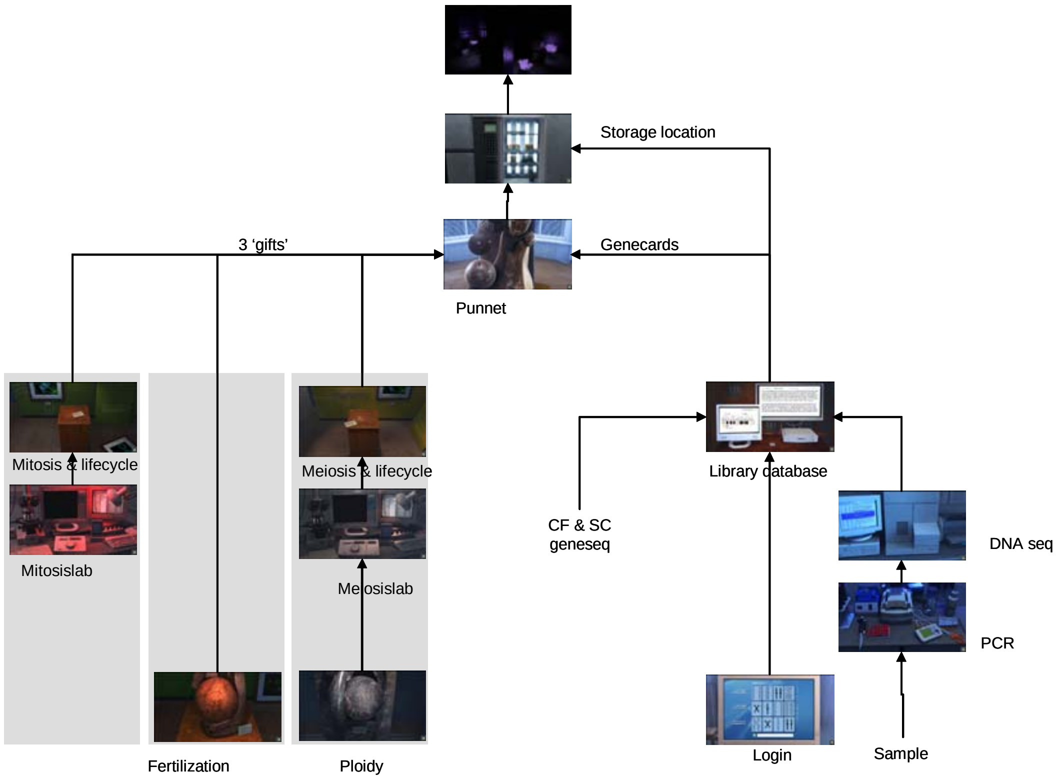
He worked as a member of her research team on what was at the time ground breaking work which would have established their reputations in the scientific community. However, at the same time, her child was diagnosed with a disorder (later dying a few hours after birth) which she somehow felt responsible for. She subsequently lost interest in her work as she dealt with her perceived guilt made more burdensome by a prevailing misconception that its is the responsibility of the mother to ensure the wellbeing of the unborn child. She closed down the project and for an ambitious career driven individual such as Mhlongu this proved an unacceptable slight to his career path especially when fame beckoned. His reasons for getting the vaccine aren't safety concerns, the subtext is his vindictiveness.

While away at a Parliamentary hearing to make a presentation to a review committee on biotechnology, as well as announce that their vaccine has promise, there is a break-in at the lab.

The vaccine the player is required to find exists in an edible form as well as the traditional form. Finding the vaccine requires learning where it is stored and uncovering just what happened to Khanyi in her grief. The player must use laboratory tools, understanding of processes associated with inheritance to discover what happened and ultimately locate the vaccine.

Having located the where the vaccine is stored, it appears that they have been beaten to the prize and that joy of revenge is being savoured. However, the very prize the player seeks is right in front of them. They must only look at it in a new light.

Puzzle Layout



Reviewer:

Date:

These questions will help to evaluate the quality of the game as a learning tool.
Thank you for your support and response.

There are a number of different question formats. Please choose an option you feel corresponds with the statement by clicking on the box. Please add comments should you wish (the space for comments is unlimited).

1. Was there anything you particularly liked about the game? What didn't you like? Do you have any suggestions for improvement?

2. Can you comment on the way that science is presented, including technology and ethics. Are there different points of view presented? Do you have any suggestions?

3. Concepts and processes were represented in a number of different ways.

   ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

4. The game provided opportunities to use learned knowledge.

   ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

5. Linking of puzzles in a hierarchy provided opportunities for reflecting on previous puzzles and how they relate to one another.

   ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

6. The story provided a relevant setting for the puzzles.

   ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

7. The story interferes with learning.

   ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

8. Was there sufficient information to follow the story? Do you have any suggestions for improvement?

9. Do you think stories are important to have in games? Why?

10. The story was sufficiently interesting to motivate players.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

11. The resolution of the story was satisfying.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

12. The game environment provided an appropriate setting for the story.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

13. The game environment encouraged exploration.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

14. The game had distinct areas which helped navigation.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

15. The game graphics were believable.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

16. Was there anything about the graphic environment that you liked? What didn't you like? Do you have any suggestions for improvement?

17. The puzzle solutions required complex thought.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

18. The similarity in the design of puzzles e.g. mitosis and meiosis was confusing.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

19. There were puzzles of varied levels of difficulty.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

20. The arrangement of puzzles was too linear.

☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

21. The relationships between the puzzles were clear.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

22. Puzzle designs suggested links between puzzles
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

23. Feedback was helpful when solving puzzles.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

24. Puzzles were interesting and challenging.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

25. The visual design of the puzzle helped with establishing goals of what to do.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

26. Attempting to solve the puzzles was frustrating.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

27. The searching of databases and use of laboratory equipment gave a sense of authenticity to the problems in the environment.
    ☐ Strongly agree ☐ Agree ☐ Disagree ☐ Strongly disagree

28. Did the puzzles feel part of the game story? Do you think this is important for games?

29. Do you have any comments on the visual design of the puzzles? Were they helpful? Can you give examples?

Thank you for your time.