

LEARNING IN TRANSFORMATIONAL COMPUTER GAMES: EXPLORING DESIGN PRINCIPLES FOR A NANOTECHNOLOGY GAME

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Abstract

Transformational games are digital computer and video applications purposefully designed to create engaging and immersive learning environments for delivering specified learning goals, outcomes and experiences. The virtual world of a transformational game becomes the social environment within which learning occurs as an outcome of the complex interaction of persons and digital resources. Engaging individuals with learning in these societal situations means concepts and skills are connected to the context and remain a powerful tool for decision making and problem solving in the world. Yet, a range of barriers need to be overcome to make a game effective for its educational purpose.

In this paper we discuss the learning and game design principles explored and used to develop a nanotechnology game. The game development experience is framed by a review of the educational theory informing our project and the questions that are driving our future research as we take the nanotechnology game into the classroom to investigate its impact on students' engagement with science. We propose that transformational will be an important component of the re-crafting of teaching and learning in the digital age and that the transformational potential of computer games can extend well beyond science and even schooling.

Introduction

This is Text – (Times New Roman, 11) Science education now has the challenge to suitably prepare all citizens and the next generation of scientists for a future with new and emerging technologies. In this contemporary context, an aim of secondary science education should be the development of scientifically literate citizens and future scientists capable of contributing to and using technologies in informed and responsible ways. The interdisciplinary nature of many new and emerging technologies means achieving this aim is dependent on teaching and learning experiences that provide opportunities for integrating knowledge from all the disciplines of science. There is a need to move students beyond the perceived facts of science and to enable them to develop conceptual understandings of contemporary science and inquiry skills while building an appreciation of the role of science in society and science as a human endeavour (ACARA, 2012).

Secondary students in developed countries such as Australia have low levels of interest in science (Sjoberg & Schreiner, 2010; Thomson & De Bortoli, 2008); yet new technologies such as nanotechnology are becoming a major aspect of developed countries economies. To assist in addressing this declining interest in science, educators and computer game designers have collaborated in the development and evaluation of a design for an online nanotechnology game. This research and development project is based on the assertion that computer and video game technologies are powerful tools for teaching and learning that reflect an opportunity for engaging twenty-first century digitally aware students. Transformational or serious games can provide entire worlds designed to help learners

adopt roles and engage story lines previously inaccessible to them. Curriculum designers can use the medium to create narratively rich virtual worlds for achieving educational goals. The youth engaged with the game can become scientists and technologists who critically engage with significant science content and inquiry skills needed to transform a virtual world and can themselves be transformed through adopting these roles (Mezirow, 2003). The aim of the project is to have secondary school students ‘play’ the game as nanotechnologists who critically engage with science content and inquiry skills needed to solve problems and make informed decisions in the game’s virtual environment.

In this paper we discuss the educational theory informing our research and the design principles used to develop an engaging educational game that aims to provide opportunities for students to consider themselves as a nanotechnologist. We also raise questions driving our future research as we take it into the classroom to investigate its impact on students’ engagement with science

Instructional Design

Educators have historically used the intrinsic motivation of game play for learning, which is not surprising as playing games is a significant human endeavour that can be traced back to early civilisations. Whereas the main aims of playing games are social and/or personal satisfaction, their engagement with our minds ensures that we also learn from the experience, although exactly what we learn may not always be clear. One of the authors spent many hours of his youth devising and playing ‘board’ games, and is convinced that this contributed significantly to his capability in probabilistic thinking that became evident in later years of schooling. At the time he did not realise he was learning anything; it was just fun making up and playing games. We have all shared positive game experiences and as such it can be expected that teachers would use the fun and leverage of games as an instructional strategy or that games would be specifically designed to teach; interestingly, the popular game of Monopoly was designed to teach economic/finance concepts. Since the early 1980s an increasing proportion of game playing in developed countries such as Australia has become computer-based, whether on dedicated platforms such as created by Nintendo, on personal computers, mobile devices, and/or over the Internet. With the increasing availability of computer devices in schools it is reasonable that teachers should consider the use of computer games to support learning; to some extent leveraging the engagement of many children with these games but to a greater degree providing a more diverse range of learning experiences.

Connecting curriculum content and game play

The intentional connection between curriculum content and game playing is perhaps the basis of what has come to be known as serious gaming. The beginning of this terminology is generally attributed to the Serious Games Initiative in 2002; however, the thinking about serious gaming developed well before this (Guillén-Nieto & Aleson-Carbonell, 2012). The terms computer-based educational games, transformational games or instructional games are used to describe using computers to support games that have been designed, or repurposed, to engage students in learning some content within the school curriculum. For example, research into the repurposing of the popular *SimCity* game identified its potential for addressing mathematics and social-science learning outcomes (Newhouse, 1992). The game initially designed for the home entertainment market spawned a series of games that were also designed for the school teaching market. So when is a game educational, transformational or serious?

Michael and Chen (2006) proposed that a serious game as one in which education, in its various forms is the primary goal rather than entertainment. Perhaps the definition given by de Freitas (2006, p. 10) for educational games is more useful, “applications using the characteristics of video and computer games to create engaging and immersive learning experiences for delivering specified learning goals, outcomes and experiences.” Enough is now known of how to create engaging and immersive learning experiences connected to curriculum outcomes to guide the purposeful design of educational games (Wouters, van der Spek, & van Oostendorp, 2011). Exactly which guidelines to follow will depend on the type of game, the pedagogical strategies supported, and the affordances of the technologies employed. In all cases the starting place is the concept of the learning environment, that is the psycho-

social environment within which learning occurs, being the complex interaction of persons and resources supporting learning (Fraser & Walberg, 1991). This is predicated on a social-constructivist view of learning in which the learner is active in constructing knowledge from experiences within such an environment. Guillén-Nieto and Aleson-Carbonell (2012) built a business simulation game starting with these premises for learning, and drawing on the associated theory of constructionism (learning occurs through the construction of representations of knowledge). They argue that a shift towards a social constructivist paradigm has been a major factor in the increased support for educational games, characterised by shifts towards learner-centred, interactive activity-based, and information processing pedagogies.

Transformational play

Keeping in mind that games are played, and the starting point that we learn from playing, the constructivist theory of transformational play has provided an excellent framework for the design of educational games as explained by Barab, Pettyjohn, Gresalfi, Volk, and Solomou (2012) for their *Quest Atlantis* multi-player virtual world game. They define the game in terms of the position of the person, the curriculum content, and the context within which the former are immersed. They explain that transformational play occurs when the player is able to take on a role in which their actions or choices change the context to allow them to relate a knowledge base (or mental model) to a problem (Barab, et al., 2012). They relate this to situated learning theory with learning emanating from activity within a context relevant to the content. It is proposed that students can readily learn from failure by continuing to play, changing their actions or choices, and achieve success. This goal and content orientation, and immersive nature support the attainment of learning outcomes while the affordances of the digital technologies employed support the fidelity of the representation of the context, transfer and management of learning.

Multimodal representation

The use of digital technologies to support games allows the use of multimodal forms of information representation, tools to manipulate those representations, and the opportunity for social interaction whether locally or globally (González-González & Blanco-Izquierdo, 2012). Modern digital technologies readily support a variety of audio-visual and tactile forms that allow games to support a range of types of interaction (e.g. viewing, listening, speaking, touching). The extended range of multimodal representations possible in digital game environments is creating different opportunities for students to experience knowledge and demonstrate what they know. When learning takes place students have experienced cognitive growth and conceptual change or development. They talk about and describe concepts in new ways with different meanings. Students construct meaning from multimodal representations and associated meta-cognitive practices (Murcia, 2012). Multimodal representations supported within the virtual learning game environment provide opportunities to address the learning styles (Guillén-Nieto & Aleson-Carbonell, 2012) or intelligence profiles of a greater range of children. Information can be represented in multiple forms, using both verbal and nonverbal modes, which assist many children to create more useful mental models. Because these representations of information are digital they can be readily edited, stored and reviewed. (Clark, Touchman, Martinez-Garza, Ramirez-Marin, & Drews, 2012).

Motivation and engagement

Where a game is being created purposefully to support learning of specific curriculum content, the instructional design of the game informs all aspects of its development. In her book on the building of games, Nicola Whitton (2010) identified a range of effective instructional design principles, particularly related to engagement, active learning, the learning context, reflection and support structures. In a later paper Whitton (2011) highlights the application of engagement theory particularly related to Flow theory with a five-factor model of *Challenge, Control, Immersion, Interest* and *Purpose*. Challenge encompasses motivation to tackle the activity, but adds “clarity as to what it involves, and a perception that the task is achievable” (p. 605). Control is defined as “the fairness of the activity, the level of choice over types of action available in the environment, and the speed and

transparency of feedback” (p. 605). Immersion is the “extent to which the individual is absorbed in the activity”; interest the “intrinsic interest of the individual in the activity or its subject matter”; and, purpose the “perceived value of the activity for learning, whether it is seen as being worthwhile in the context of study” (p. 605). Because these factors are all entirely related to characteristics of the user, it underlines the importance of involving users and user testing throughout the design processes of game development.

Incorporating motivators for play into the game design encourages student engagement with the educational content. Whitton (2010, p.146) highlights the importance of the following motivational elements in game design.

- An elements of competition can motivate people to play
- A compelling story (mystery/dilemma)
- Puzzle solving, ongoing, riddles, problems to heighten curiosity
- A sense of community which encourages players to talk to one another e.g., discussion boards and other online community spaces
- Opportunities for players to be creative and use lateral thinking which allow players to shape the direction of the game, creating artefacts, posters, video stories etc.)

Furthermore, González-González and Blanco-Izquierdo (2012) argue that good games “convert their users into creators, and not mere receptors” so that their “actions influence or build the game’s universe” (p. 254). This is the active learning instructional design concept to which virtual world role-playing games lend themselves. They also associate this with a “cycle of mastery” scaffolding the user’s experience with knowledge and tools to “allow them to build generalizations that will enable them to face more complex problems” (p. 254). In instructional design terms this is more than just providing access to information, this means building in mechanisms to allow for representation and connection of information, theorising, testing and reflection with collaborative opportunities. Computer networking (locally and globally) affords connection within games to other players with competitive or collaborative interaction supported. This social dimension is as important as other dimensions such as personal engagement in transforming play into purposeful learning (González-González & Blanco-Izquierdo, 2012).

A model of participation for developing scientific literacy

These dimensions of learning design theory have shaped the aim and rationale for developing the nanotechnology game that is the focus of this paper. A problem driving the development of the current nanotechnology game is that most young people are disconnected from science and scientific concepts; they have little idea of what science sets out to achieve, what a scientist does, or how science theory is created and used. They do not perceive that the science they experience at school relates to their world outside school; they cannot take on a science perspective. Yet, in modern developed countries science and technology shape and drive everyday life and as such active citizens require at least some level of scientific literacy. Teaching and learning science should reflect the way science operates in society and ensure individuals achieve a general, broad and useful understanding of science that contributes to their competence and disposition to use science to meet the personal and social demands of their life at home, at work and in the community (Murcia, 2007). Today’s citizens should be able to locate, analyse and critique information, to form their own opinions and make informed decisions.

In applying game design theory to the development of students’ scientific literacy and then specifically the construction of useful mental models of the science of nanotechnology, an immersive virtual world game model based on transformational play theory is deemed appropriate. By positioning a student in a transformational game as a scientist, where they interact with a virtual world that is much like their real world, to solve meaningful problems using scientific methods connected with embedded knowledge and concepts, is likely to better engage them with science and allow them to construct more useful mental models of related knowledge (Kaufman, Sauv e, & Renaud, 2011). Engaging

students with learning science in societal situations means concepts and skills are connected to the situation and arguably remain a powerful tool for decision making and problem solving in the world.

The following aspects of scientific literacy have informed the game development:

- apply science through technologies in informed and responsible ways;
- think critically about the role of science and technology in society;
- use science concepts and inquiry skills for informed decision making in a societal context;
- problem solve to transform the virtual world;
- consider potential ethical issues associated with the development and implementation of nanotechnology; and,
- build awareness of the political and cultural contexts of science research and commercialization.

The development of students' scientific literacy within the Nanotechnology game is based on a model of participation that involves intentionally leveraging the three interconnected elements of person, content, and context. Specifically, when creating spaces to afford transformational play, the aim is to create experiences that position these elements in the following ways (Barab, Gresalf, Ingram-Goble, 2010, p. 526).

1. Person: positioning players as protagonists with the responsibility of making choices that advance the unfolding story line in the game.
2. Content: positioning the understanding and application of science and technology concepts as necessary if players are to resolve the game-world dilemmas successfully.
3. Context: positioning contexts as modifiable through player choices, thus highlighting consequences and providing meaning to players' decisions.

Through the virtual game environment the student acts and thinks like a scientist by postulating hypotheses, collecting and analysing information, reasoning and constructing arguments, which connect the physical and cognitive experience with the social context. The digital technologies afford a realistic but safe virtual context for any science inquiry, even those such as nanotechnology that would not be accessible at school (Spires, Rowe, Mott, & Lester, 2011). Transformational games also support the social nature of real science inquiry and highlight science as a human endeavour where students can move beyond memorising isolated concepts to considering the moral and ethical decision making process.

Software for creating games

A potential barrier to the effective nanotechnology game creation is the overhead of implementing the chosen game design. The overhead costs are of two types. First, implementation has a resource cost in terms of development time and money. Second, the difficulty of making changes to the game can affect the final quality, as game parameters often need to be adjusted based on play testing in schools with students. Finding solutions and options to overcome these barriers is integral to the success of the project. We investigated and compared the various tools available to game developers, which minimise development effort by providing a framework of generic functionality, along with tools that allow the developer to add in the functionality specific to their game.

In order to understand these tools, we firstly examine the tasks that a computer game program needs to accomplish. A typical real-time interactive computer game takes input from the player via some input device, and produces its output on a visual display device as a sequence of static image frames. In between of drawing each frame to the screen, the positions of the objects in the world, and any game logic are updated. The generic tasks that need to be performed in a loop include:

- Get input from the player.

- Find the new position of each object in the next frame.
- Check for colliding objects.
- Run the game logic.
- Draw the next frame.
- Repeat.

For many games, the only unique aspect to this is the game logic – literally the rules of the game. For the other tasks, standard off-the-shelf components are available. A set of such components is known as a game engine. Commercial game engines use a combination of off-the-shelf and custom components to provide the generic functionality and provide a means for the game developer to insert custom game logic. This is usually through a scripting language aimed to make programming simpler (as opposed to the game engine implementation language, whose choice is aimed at making the engine fast and efficient), or through visual tools. The game engine’s scripting tools allow for fast tuning of game parameters, with the designer often being able to see the effect of a changed script instantaneously in the game.

The other custom aspect to a game, besides game logic program code, is the assets. Assets are the entities that populate the world, including static and animated 3D objects, the graphics used for the user interface, and the music and sound effects. A good game engine provides a set of tools to enable assets to be added from their authoring software, adjusted in the game engine, and hooked up to the game logic code.

DevMaster.net is a database of game engines, listing features and including user reviews, at time of writing containing information on 350 game engines. Game engines can be distinguished along several lines, including price, quality of graphics produced, ease of use of the tools, hardware platforms targeted, and level of documentation. Three popular game engines are Unreal Engine, and CryENGINE3 and Unity 3D.

Unreal Engine (Epic) is a commercial grade engine behind the successful Unreal Tournament series of games among others. Unreal Engine won Game Developer Magazine’s Front Line Awards Game Engine category six times in the seven years (2006-2011) of that category (Game Developer Magazine, 2012). Currently, the latest release of the engine is Unreal Engine 3. The full Unreal Engines large license cost is a barrier to all but the top-tier game developers, but a more accessible version, the Unreal Development Kit (UDK), first released in 2009, is offered for free, with royalties payable on released commercial games. CryENGINE 3 is another commercial engine, behind the Crysis series games. It is often among the Front Line Awards finalists, but has never won the engine category though it is considered superior to Unreal Engine 3 in terms of quality of graphics (Zielke, 2010). Like Unreal Engine, the cost to license the full engine is prohibitive, but a low cost option is available in the CryENGINE3 SDK. The CryENGINE3 Free SDK was made available from 2011 for free for educational institutions and non-commercial use. At the time of writing, the CryENGINE3 Free SDK cannot be used to make shippable games and details of the royalty structure are unreleased. In contrast to UDK and CryENGINE3 SDK, which came out of commercial quality engines, Unity3D started as a hobbyist engine, however through its ease of use gained popularity as a teaching tool and is subsequently becoming more popular in commercial game development. Regularly a finalist in the Front Line Awards, its strength is the variety of platforms supported (Zielke, 2010). The features of UDK, CryENGINE3 SDK, and Unity 3D are compared in Table 1.

Table 1: Features of three popular game engines.

	Unity3D	Unreal Development Kit (UDK)	CryENGINE3 FreeSDK
Price	\$1,500USD per seat, no royalties.	Free for educational or non-commercial use. Royalties apply for	Free for educational or non-commercial use. Royalties apply for

		commercial work.	commercial work.
Scripting Language	Javascript or C#	UnrealScript	Lua
Visual Scripting	Visual parameter modification only	Kismet visual scripting tool	Flowgraph visual scripting tool
Platforms targeted	PC, Mac, & Browser. Android and iOS with additional purchase.	PC and iOS	PC
Multiplayer	Multiplayer online	Multiplayer online	Limited multiplayer

For the development of the nanotechnology game, Unity3D game engine was selected. The primary reason is that it supports a variety of platforms. For delivery of the game to computers in schools, a variety of hardware and software can be expected. To keep the game as platform agnostic as possible, we chose a browser-based distribution options. This option involves hosting the game on a server, and the students accessing the game through a web browser, with the Unity web player plugin, using the Internet. Due to the growing popularity of mobile devices, such as the iPad, in schools, the use of Unity3D as the game engine also allows future release of the nanotechnology game for these platforms.

Design principles in the Nanotechnology Game

It is evident in the preceding discussion that successful game development and research demands interdisciplinary collaboration, as illustrated in Figure 1.

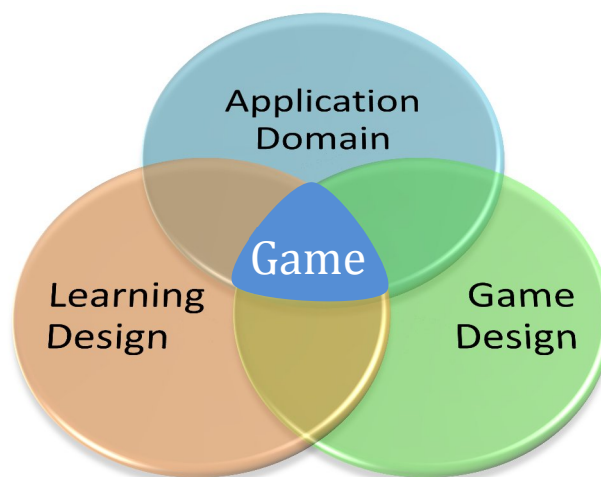


Figure 1: The intersecting dimensions of game development and research

Every transformational game research team requires education specialists expert in learning design within the digital medium who understand human cognition, engagement and motivation; and in

addition, game design specialists who understand the elements required to make the game, fun and engaging and who can work closely with programmers and graphic designers. These two core dimensions are essential in any game research and development project. The third critical dimension to effective game development and research is the application domain. These are the people who know the richness of the context and detail of the domain content, skills, attitudes and inherent values.

From the outset of the nanotechnology game conception stage, it was important to begin with a team that brought the different skills together to produce an informative and entertaining game. We established the following game development roles to ensure balance across the three domains illustrated in Figure 1.

- **Subject expert:** In creating a game centred on nanotechnology, it is important to understand the scope of what is achievable within the realm of nanotechnology. With a team member equipped with a deep understanding of nanotechnology, it is felt that the full breadth of this field can be called upon, without straying into speculative fiction.
- **Educationalist:** As this is an educational game, it is important to include a team member with an understanding of the educational goals, and how the target student group can be engaged with the game's content. As with the subject expert, it is the educator's role to keep the game on track to deliver a factual, informative game aligned with curriculum.
- **Writer:** It is the role of the writer to take the ideas or information provided by the subject expert and educator, and to build it into an engaging and cohesive narrative.
- **Graphic designer:** The graphic designer's role is to take the work developed by the writer and knowledge based roles, and to design a user interface that fully conveys the information in a manner that will most effectively engage, instruct and entertain the player.
- **Game designer:** Finally, the role of the game designer is to take everything produced by the rest of the team and to find a technical solution to packaging the designs into a product that will run reliably in the specified IT environment.

The first challenge for the team was to arrive at a game concept that will successfully balance the information and entertainment aspects of the product. Making the game too information heavy could result in a product that is essentially indistinguishable from a PowerPoint display. Yet, focussing too heavily on the entertainment aspects, may cause the player to miss key science and technology information, or worse, lead the player to constructing misconceptions.

As a first step a 'think-tank' was held with several external parties who had experience in the areas of science communication, nanotechnology education, education through multimedia and e-research. The key questions used to focus the discussion and generation of ideas were; what is nanotechnology and what storylines/scenarios or dilemmas could be used to situated players game experience and engage them with nanotechnology? Participants were encouraged to think creatively, explore ideas by talking in groups and to draw pictures and sketch ideas on poster paper.

A major theme emerging from the think-tank was the importance of demonstrating through the game that science is not an abstract discipline only existing within text books and the walls of the classroom, but rather that it is a human endeavour conducted by real people in a range of professions aiming to better understand and improve society. Much associated discussion was held on the nature of the player character within the game and it was perceived to be important that the student player would control a character that is readily relatable, and if possible, customisable by the player. The purpose of this is to enhance the student player's identification with the game character, promoting the message that science research is a viable career path. Additionally, the player's interaction with non-player characters (NPCs) was regarded as an important means for seeking information and engaging with science as an inquiry process. By populating the game with science oriented NPCs, and by scripting dialogue that conveys that the NPCs react positively to the player's observations, reasoning and decisions, contributes to developing a positive perception of scientists and their role in society. This is in direct contrast to the relatively standard popular media representation of scientists as eccentric or malevolent characters, which can contribute to unproductive stereotypical views of science and

scientists; potentially alienating young people from learning science and entering science careers.

During the think tank, the concepts for the game almost universally ran towards a ‘world in peril’ theme. This serves the dual purpose of having a high stakes entertainment aspect, but also to ground the game in an aspect of our reality. That is, taking a familiar environment, such as a city, and using that sense of familiarity to present a conceptually challenging topic such as nanotechnology. Many of the proposed game topics raised during the think tank centered around two distinct themes. The first theme was how the application of nanotechnology could be taken in different directions such as medical applications, material science and construction, environmental protection, entertainment and security services and protection. The second theme concentrated on the inner workings of nanotechnology, such as how nanoparticles can be made to interact to treat cancer. From this discussion it is apparent that producing a game that successfully conveys the concepts of nanotechnology requires a high level view of applications to ensure that students gain an appreciation of the potential scope of nanotechnology applications in the future, while at the same time also conveying key science concepts and the detail of what happens at the nano-scale with the technologies explored in the game world.

Taking the conclusions of the think tank and applying the expectations of the Australian Science Curriculum (ACARA, 2012), the game that has taken shape is one in which the player explores the possible uses of nanotechnology to address real world problems issues or dilemmas; in doing so students experience science as a human endeavour. By engaging in dialogue with NPCs, the player becomes familiar with the possible applications of nanotechnology, and also with the issues affecting their world. The player can then enact measured responses to this input, by reviewing the possible solutions and choosing specific fields of research to be pursued by them in an area of the virtual city. The consequences of the actions of players in game research will be evident in the world, displayed both graphically and implied through further conversations with the NPCs. The player will have opportunities to pursue research paths that will have varying levels of efficacy against the game problem or issue. This feedback allows the player to review the consequences of their actions, and plan subsequent rounds of research action. A second layer of the game contains key science and nanotechnology concepts embedded with game play that requires players to engage in nanotechnology experimentation or simulations. These areas of the game will present the player with stylised demonstrations of what occurs at the nano-scale.

The design of the nanotechnology game is modular in nature as it is built up by a series of mini-games situated within the virtual city. This design approach allows for continued development and re-development, as new mini-games can be added as advancements in nanotechnology occur and/or there are changes to the curriculum. Through meeting the objectives of these mini-games, the player will gain an appreciation of the interconnected way in which scientific and technological advancements are achieved. The overall design of the game will be based on a time constraint of a 50 minute play-through for a mini-game, ensuring that the game is playable within a fairly standard secondary school learning session. Players cannot explore all options or mini-games within one session. It is anticipated that this will have two effects; firstly that students will want to return to the game, and secondly, it will prompt the student to discuss and compare their results with other players in order to ascertain the effects of different decisions made within the game.

Questions to ask when taking the game to the classroom

To leverage the curriculum learning outcomes from an educational game, scaffolding and support from the teacher, peers and other resources (e.g. help systems and knowledge databases) are required. This is what Whitton (2010) refers to as the teacher providing a “learning package that surrounds an educational game, debriefing, post-game discussion and reflection” (p. 95). Thomas, Barab, and Tuzun (2009) explain that how a game is implemented within the curriculum by the teacher is critical to the learning outcomes realised, and in fact whether the game is even used. With this in mind a section of playable game will be trialled with lower secondary science students and their teachers. Teachers volunteering to trial the game will be interviewed to determine their beliefs about effective

teaching and learning practises. The interview should reveal if they are committed to social constructivist teaching principles and interest driven learning, which is an underlying assumption of the transformational game strategy. Students will be observed playing the game, and later interviewed, in order to assess how the game is working, and whether it is engaging students with the nanotechnology concepts and impacting on their development of scientific literacy competencies. Pre and post game play questionnaires will be used to determine if the game provides background knowledge which enhances the students understanding of nanotechnology and their interest in future science related careers. In addition, the feedback from student interviews will be used to refine and further develop the game.

Researchers will also work with teachers to refine the pedagogy in the game and how it's used in the classroom. Investigations will focus on strategies for supporting student discourse in and around the game play that facilitates more conscious reflection on the mental models evoked. It is anticipated that collaboration with classroom teachers will be integral to refining the pedagogy in the game and identifying how it is best used in the classroom.

Conclusion

Improving the relevance and interactivity of educational learning resources and pedagogy through a purpose-designed game should increase students' awareness of nanotechnology, future career options and importantly contribute to generating an interest in science. Motivating students to engage with contemporary science concepts and skills is an integral part of ensuring we have the predicted two million workers needed in the next five years for nanotechnology industries (Roco, 2006). It is unlikely that many students were ever suited by the information-transmission model of schooling with the solitary passive reception of pre-constructed packets of spoken or printed information. Certainly decades of data attest to the lack of success of this approach for most children; it is likely that at best one or two styles of learning or intelligences were accommodated. Compounding this lack of success, people now have access to a range of very sophisticated computer games, global communications, and repositories of relevant information at their fingertips with which to compare their experiences at school. What if all that educational potential they experience using digital technologies outside school was leveraged as part of their schooling, perhaps the skills of the teacher would craft far superior outcomes for a much greater range of individuals.

We propose that transformational games such as the nanotechnology game described in this paper will be an important component of the re-crafting of teaching and learning in the digital age. The transformational potential of computer games can extend well beyond science and even schooling. The design principles described in this paper can be used to develop transformational games in a wide range of application domains. Professional development and training services for industries as diverse as health care, mining, occupational health and safety and community awareness programs are all context rich and require situated learning for sustainable improvements and capacity building. Transformational game research and development is a rapidly growing area both nationally and internationally that can offer significant improvement to traditional learning and development fields.

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