

What are the learning affordances of 3-D virtual environments?

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Abstract

This article explores the potential learning benefits of three-dimensional (3-D) virtual learning environments (VLEs). Drawing on published research spanning two decades, it identifies a set of unique characteristics of 3-D VLEs, which includes aspects of their representational fidelity and aspects of the learner–computer interactivity they facilitate. A review of applications of 3-D VLEs is presented, leading to the identification of a series of learning affordances of such environments. These affordances include the facilitation of tasks that lead to enhanced spatial knowledge representation, greater opportunities for experiential learning, increased motivation/engagement, improved contextualisation of learning and richer/more effective collaborative learning as compared to tasks made possible by 2-D alternatives. The authors contend that the continued development of and investment in 3-D games, simulations and virtual worlds for educational purposes should be considered contingent on further investigation into the precise relationships between the unique characteristics of 3-D VLEs and their potential learning benefits. To this end, they conclude by proposing an agenda or ‘roadmap’ for future research that encompasses empirical studies aimed at exploring these relationships, as well as those aimed at deriving principles and guidelines to inform the design, development and use of 3-D virtual environments for learning.

Introduction

Three-dimensional (3-D) technologies have become a fundamental element of almost all modern computer games, including most of the current massively multiplayer online games (MMOGs) such as *World of Warcraft*. They are also central to the new generation of immersive virtual worlds, such as *Active Worlds* and *Second Life (SL)*. Internationally, educators and educational institutions envisage great potential in the use of 3-D simulations, games and virtual environments (VEs) for teaching and learning, as they provide the possibility of rich learner engagement, together with the ability to explore, construct and manipulate virtual objects, structures and metaphorical representations of ideas. Much time, financial and other resources are therefore being devoted to efforts aimed at harnessing the pedagogic potential of these technologies, with the academia, industry and government working to develop new platforms, tools and resources to support these endeavours (de Freitas, 2006). However, very few empirical studies have been conducted that have documented enhanced post-test knowledge and/or skills of students using desktop-based 3-D environments over those using equivalent 2-D technologies. The primary aim of this article is to critically examine the pedagogical benefits of 3-D virtual learning environments (3-D VLEs) through a review and analysis of a range of potential and actual applications of such environments.

3-D VLEs

A 3-D VE can be defined as an environment that 'capitalizes upon natural aspects of human perception by extending visual information in three spatial dimensions', 'may supplement this information with other stimuli and temporal changes' and 'enables the user to interact with the displayed data' (Wann & Mon-Williams, 1996, p. 833). Three-dimensionality, smooth temporal changes and interactivity are the most important features that distinguish 3-D VLEs from other types of VLEs, such as those provided by a learning management system (eg, Blackboard or Moodle). The present article is primarily concerned with 3-D VLEs that can be explored using standard personal computer (PC) hardware commonly available in schools and homes, often termed 'desktop virtual environments', although the discussion may also apply to 'immersive virtual environments' such as those requiring the use of specialised hardware in the form of head-mounted displays, multi-wall Cave Automatic VE systems (better known by the recursive acronym 'CAVE'), high-degree-of-freedom input devices and video tracking systems.

In his literature review on 3-D VEs and game environments, Jacobson (2006) cites several studies conducted since the mid-1990s, whose results suggest that immersive 3-D VLEs, if appropriately designed and used, may provide 'value-added' learning over 2-D technologies used to deliver equivalent educational content. However, the costs associated with the equipment and computational power required for these applications have made them largely prohibitive in mainstream settings. Thus, the findings of these studies have had little practical impact to date in spite of their theoretical significance. In recent years, the ubiquity of multimedia and Internet-capable PCs has led to a resurgence of interest in web-based virtual reality (VR). The highly interactive and

multi-player engagement afforded by commercially available 3-D games has attracted millions of users worldwide to use these technologies, and given rise to a sizeable economic market that continues to fuel further research and development in this area. It is therefore not surprising that large numbers of educators across the globe are attempting to harness the educational power of these technologies, excited at the prospect of 'co-opting' (Buchanan, 2003) the tools and toys students already use for communication and entertainment to help them learn better. Commercial, off-the-shelf 3-D games are being repurposed and adapted for use in classrooms (Gikas & Van Eck, 2004; Sandford, 2006; Van Eck, 2006), while new, educational games and VEs are being developed to address specific curricular content (see for example, Barab, Thomas, Dodge, Carteaux & Tuzun, 2005; Jacobson, Kim, Lee, Lim & Low, 2008; Squire, Barnett, Grant & Higginbotham, 2004).

Nevertheless, amid the current hype surrounding desktop 3-D technologies, a critical look at the research to date suggests that the case for how these technologies support learning remains equivocal, with the learning outcomes achieved in projects in this area being discussed in very generic terms (Jacobson, 2006). Though a number of researchers (for example, Gee, 2003; Steinkuehler, 2004) have documented educationally relevant outcomes, there is little conclusive evidence that attests to the specific learning benefits of 3-D VLEs, that is, benefits that emanate particularly from the 3-D aspects of these environments (McFarlane, Sparrowhawk & Heald, 2002; McLellan, 2004). This article seeks to isolate the distinguishing characteristics of 3-D VLEs and the potential benefits that may accrue from the learning tasks they afford, based on a systematic analysis of research literature and project reports in this area. Later in the article, the derivation of a list of affordances of 3-D VLEs for learning will serve as a platform for a proposed research agenda (an affordance of a tool is essentially an action made possible by the availability of that tool). This agenda will help establish a sound theoretical base to support the work of both researchers and practitioners interested in the use of 3-D games, simulations and virtual worlds for learning.

Distinguishing characteristics of 3-D VEs

3-D VLEs exhibit a unique set of characteristics from a pedagogical point of view. Hedberg and Alexander (1994) suggest that their most important defining feature is the 'transparent interface with which the user directly controls the objects in the context of the virtual world' (p. 215). In identifying the features of VEs that make them distinct from interactive multimedia, they name three aspects of VEs that contribute to this transparency and through which such environments have 'the potential to offer a superior learning experience' (p. 218): increased 'immersion', increased 'fidelity' and a higher level of 'active learner participation'.

There is some agreement between Hedberg and Alexander's ideas and those of White-lock, Brna and Holland (1996), who propose a theoretical framework in order to explore the relationship between VEs and conceptual learning. Their framework, which extends the work of Zeltzer (1992), includes the identification of three properties or dimensions of 3-D VLEs, namely 'representational fidelity', 'immediacy of control' and

'presence'. 'Fidelity' appears as a factor in both Hedberg and Alexander's and Whiteberg *et al*'s models, and Whitelock *et al*'s 'immediacy of control' relates very closely to Hedberg and Alexander's 'active learner participation'. Hedberg and Alexander use the term 'immersion' to encompass both the physical aspects of the environment and the psychological sense of being in the environment, while Whitelock *et al* use 'presence' in a similar way, ie, to include both the objective characteristics of the environment and the user's subjective experience. Consequently, Hedberg and Alexander's property of immersion can be equated with Whitelock *et al*'s presence dimension.

Both Hedberg and Alexander and Whitelock *et al* focus on the characteristics of single-user VEs, which is to say they are concerned primarily with the way in which an individual interacts with such an environment on his or her own. Brna (1999), on the other hand, extends his earlier work with Whitelock and Holland (ie, Whitelock *et al*, 1996) to propose a framework that incorporates the social factors involved in the use of multi-user VEs (MUVEs). His six-dimensional framework includes Whitelock *et al*'s 'representational fidelity', 'immediacy of control' and 'presence', as well as three additional elements: 'social fidelity' (including social familiarity and social reality), 'immediacy of discourse' and 'social presence'.

Many authors have stressed the importance of immersion and presence, suggesting that these are critical features distinguishing VEs from other types of computer applications (McLellan, 2004; Mikropoulos, 2006; Mikropoulos & Strouboulis, 2004). In early writings about VEs, there was a tendency to use these terms interchangeably; subsequently, debates occurred in the literature about the definitions of these terms (see for example, Slater, 1999; Witmer & Singer, 1998). We concur with Slater (1999, 2003, 2004), who defines presence as the subjective sense of being in a place, and immersion as the objective and measurable properties of the system or environment that lead to a sense of presence. In other words, immersion relies on the technical capabilities of VR technology to render sensory stimuli, whereas presence is context-dependent and draws on the individual's subjective psychological response to VR. The latter is dependent on a range of factors including, but not limited to, the user's state of mind (Slater, 2003).

In looking more closely at the immersive properties of an environment, we argue that it is essentially the fidelity of the representation, along with the types of interactivity available within the environment, that will lead to a high degree of immersion and consequently, a strong sense of presence. For this reason, we do not believe that immersion should be treated as a unique property. The dependency of immersion on other aspects of the environment is noted by Hedberg and Alexander (1994), who maintain that 'the interaction of representational fidelity with sensory, conceptual and motivational immersion needs to be examined to determine the complexity of sensory input necessary to establish the learning outcome' (p. 217). Similarly, we do not believe that presence should be deemed a unique property because it occurs as a result of the fidelity and the interactive capabilities of the environment.

While sense of presence in a virtual world or environment has traditionally been used to refer to a user's perception of 'being there' (Ellis, 1996; Schroeder, 2002), a more recent area of research entails the examination of co-presence, defined as the sense of 'being there together' with other geographically dispersed users. The concept of co-presence is considered by many to be an extension of social presence, which emerged as a topic of interest within the field of human-computer interaction in the 1970s (Short, Williams & Christie, 1976) and which was included in Brna's aforementioned framework (see also Biocca, Harms & Burgoon, 2003; Garau, 2003). It is arguable that many 3-D MUVes support high levels of co-presence, owing to the fidelity or realism of the environments within which the shared sensory experiences occur and the facilities that are available for spatial and other forms of non-verbal communication. Hence, as with sense of presence, co-presence may be said to be a result of the various characteristics of the environment rather than being a characteristic of VEs as such.

An important aspect of the use of a 3-D VE is the way in which users, through their embodied actions and social interactions within the environment, construct online identities for themselves. In many 3-D VEs, each user is depicted by an 'avatar' that provides a visual representation of his or her real or surrogate identity and appearance. The sense that the avatar being controlled by the user is a portrayal of himself or herself (or of an alternative self) that he or she consciously or unconsciously creates within the environment is important for supporting a rich sense of psychological immersion in the performance of tasks, as well as for supporting deep levels of communication, collaboration and relationship building (de Freitas, 2006, 2008). Riva (1999) examines the psychosocial issues involved in communication and action in VEs and identifies the relationship between embodiment and presence as an important issue along with the relationship between identity construction, projection and perception. Dickey (2002) identifies three aspects of the user's experience that contribute to identity construction: presence (including both the physical state of presence as well as the social impression one makes), representation (including the visual appearance of the person's avatar, along with their identifying name or description) and embodiment (including their physical actions along with the social positioning of these actions). Importantly, although the ability for the user to construct and portray an identity within the environment is important, we take the view that rather than this being a unique characteristic of 3-D VEs, it is, in a way that is similar to the case with presence and co-presence, a consequence of the representational fidelity and learner interactions facilitated by the environment.

Adopting the perspective that representational fidelity and learner interaction are unique characteristics of 3-D VEs, whereas construction of identity, sense of presence and co-presence are characteristics of the learner's experience as a result of these environment characteristics, Figure 1 depicts an initial model of learning in 3-D VEs. In this model, representational fidelity should be taken to incorporate aspects of both single-user and multi-user environments, as well as Brna's concept of social fidelity. Similarly, learner interaction should be taken to incorporate individual, collaborative and communicative actions, and consequently, Brna's concept of immediacy of discourse.

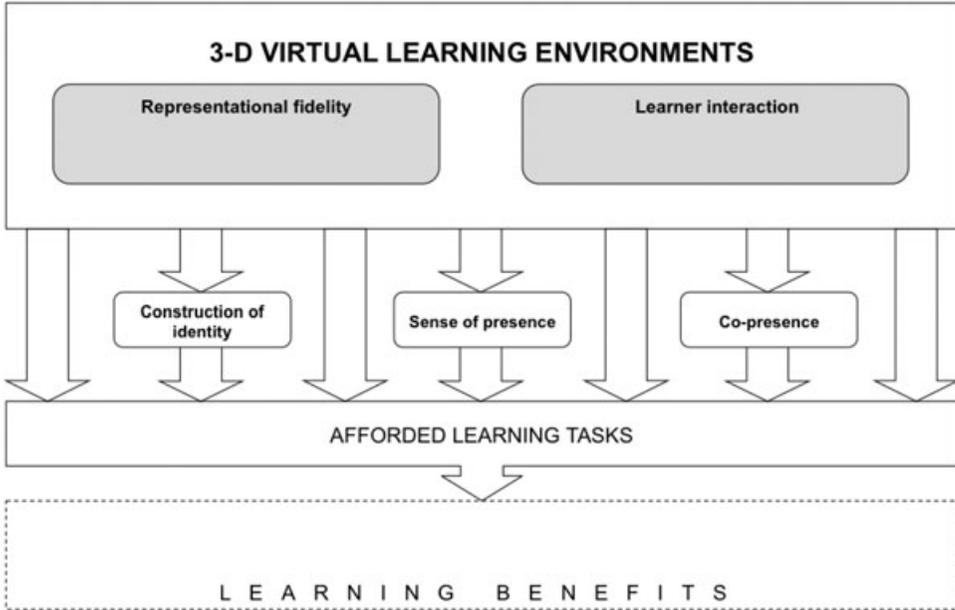


Figure 1: Initial model of learning in 3-D VLEs

Table 1: Distinguishing characteristics of 3-D virtual learning environments

Category	Characteristics
Representational fidelity	<ul style="list-style-type: none"> • Realistic display of environment • Smooth display of view changes and object motion • Consistency of object behaviour • User representation • Spatial audio
Lerner interaction	<ul style="list-style-type: none"> • Kinaesthetic and tactile force feedback • Embodied actions including view control, navigation and object manipulation • Embodied verbal and non-verbal communication • Control of environment attributes and behaviour • Construction of objects and scripting of object behaviours

The two broad categories of representational fidelity and learner interaction can be further elaborated on to identify the specific aspects of 3-D VLEs that distinguish such environments from other interactive learning resources (Table 1). The two most important visual aspects of the representational fidelity of a 3-D VE are realistic display of the environment and smooth display of view changes and object motion. The display of objects using realistic perspective and occlusion, as well as realistic texture and lighting, allows for realism that can approach photographic quality if the 3-D model is defined

with sufficient detail. However, even when the images do not approach photographic quality, with sufficient frame rates, the image changes that reflect the viewer's motion or the motion of objects can appear smooth enough to provide a very realistic experience. Another aspect of the fidelity of the representation is the consistency of object behaviours, including the way that they respond to user actions and their autonomous (or modelled) behaviours.

A fourth aspect of representational fidelity is user representation, which involves the depiction of the user as an avatar through which he or she is able, according to Dickey (2002), to develop and project an online identity. Benford, Bowers, Fahlén, Greenhalgh and Snowdon (1995) illustrate the complexity of user representation in 3-D VEs, deriving a list of characteristics to be considered in user representation design. This depiction of users is an important element of the fidelity of the representation because it helps create a sense of co-presence in the environment, which in turn enriches the social interactions occurring (Schroeder & Axelsson, 2006).

Traditionally, applied research on 3-D VEs focused primarily on the visual aspects of the representation, with research on environments incorporating other sensory information confined to high-end laboratory systems. More recently, the availability of '3-D audio' technologies (Adler, 1996) that provide spatial perception of sounds has become almost ubiquitous in mainstream 3-D VE applications (Bowman, Kruijff, LaViola & Poupyrev, 2004); these technologies can be used to direct the user's attention and enhance the realism of the virtual experience by providing various directional and distance cueing effects (Bormann, 2005). Haptic technologies that allow users to feel force and pressure while interacting with the environment are also becoming commonplace (Bowman *et al*), particularly as a feature of many popular videogame consoles. For some years, haptics have been employed as a learning tool for motor skill development in fields such as surgical training (Gunn, Hutchins, Stevenson, Adcock & Youngblood, 2005; Ström *et al*, 2006), in which it is used to reproduce an expert's skill in the form of tactile and kinaesthetic perceptions using the expert's temporal position, velocity and force information; they are now also being applied to the learning of abstract concepts in 3-D VEs (Harvey & Gingold, 2000; Jones *et al*, 2004; Minogue, Jones, Broadwell & Oppewall, 2006). Consequently, it is now reasonable to include kinaesthetic and tactile force feedback along with spatial audio as characteristics of the representational fidelity of the environment.

In relation to learner interaction, an important aspect that is unique to 3-D VEs is the ability to undertake embodied actions, including view control, navigation and object manipulation. Dall'Alba and Barnacle (2005) have argued that traditional (ie, web-based) online learning environments tend to be designed to facilitate disembodied ways of learning and knowing, which is at odds with contemporary epistemological theories that emphasise contextual, embodied knowledge. 3-D VEs have the potential to address this through user representation (discussed earlier) and embodied action. Dickey (2002) also asserts that embodiment is an important element in the construction and portrayal of an online identity.

Looking specifically at 3-D environments with multi-user capabilities, these environments provide the facility for users, through their avatars, to engage in embodied verbal communication through text and voice, as well as embodied non-verbal communication in the form of gestures and facial expressions. Though verbal communication *per se* is not unique to 3-D environments, the embodiment afforded by 3-D MUVes provides the added ability to align gesture and actions with written and/or spoken words. An additional interactive characteristic is the way in which the learner can be given control over the attributes and behaviour of the environment, including, for example, the modification of time and gravity parameters. Last but not least, much recent attention has been given to the learning benefits that may arise from enabling learners to construct their own virtual places and/or objects (see for example, Antonacci & Modress, 2008; Boulos, Hetherington & Wheeler, 2007) by capitalising on the extensibility of 3-D virtual world and gaming platforms and the ability for the user to perform 'modding' (Hedberg & Brudvik, 2008) and scripting of object behaviours. Table 1 brings together these four aspects of learner interactivity, along with the six aspects of representational fidelity identified earlier in this section, as a set of 10 distinguishing characteristics of 3-D VEs.

The learning affordances of 3-D VEs

Having identified the unique characteristics of 3-D VEs, we will now attempt to identify a set of contributions to learning that potentially arise from tasks afforded by such environments. The term 'affordance' was first coined by Gibson (1979), who used it to refer to the functional properties that determine the possible utility of an object or environment (cited in Salomon, 1993). According to Greeno (1994), 'an affordance relates attributes of something in the environment to an interactive activity by an agent who has some ability' (p. 338). A number of authors have also used 'affordance' in educational contexts to describe the relationships between the properties of an educational intervention and the characteristics of the learner that enable certain kinds of learning to occur (Kirschner, 2002), while others stress the importance of analysing how the affordances of information and communication technologies (ICTs) can be used to facilitate particular approaches to teaching and learning (see for example, Conole & Dyke, 2004). Bower (2008) proposes a methodology for matching the affordance requirements of learning tasks with the technological affordances of ICT tools, which can be used to help guide and inform the processes of technology selection and learning design. We concur with Bower's implicit conception of affordances while also acknowledging that the technologies themselves do not directly cause learning to occur but can afford certain learning tasks that themselves *may* result in learning or give rise to certain learning benefits.

In this section, a range of proposed and actual applications of 3-D VEs for learning are reviewed, leading to the identification of five learning affordances of such environments. These affordances represent the theoretical learning benefits of 3-D VEs explicitly and/or implicitly purported by the authors in the literature; our choice of the term 'affordances' in preference over 'benefits' or 'advantages' is in recognition of the aforementioned view that it is the tasks, activities and underpinning pedagogical strategies

supported or facilitated by the technology rather than the technology itself that have an impact on learning; additionally, the use of a particular technology or media form does not guarantee the yield of specific learning outcomes or benefits (see Clark, 1983, 1994a, b).

The applications reviewed have been grouped into three broad categories: 3-D simulations and microworlds, 3-D environments as interfaces to learning resources and 3-D multi-user VLEs. It is important to note that these categories have been used only to help structure the review—we recognise that they are not mutually exclusive in that a particular resource could fit into more than one category.

3-D simulations and microworlds

Simulations have been used as part of computer-assisted learning materials for at least three decades, with SimCity (Wright, 1989) being one of the earliest and most popular examples. Simulated 3-D environments modelled on real places and objects have the potential to provide an enhanced sense of realism and a greater sense of presence as compared with non-3-D environments. Their fidelity is such that where barriers exist for visiting the real place, immersion in the 3-D VE can be a viable alternative. For example, Alberti, Marini and Trapani (1998) describe a 3-D VE modelled on a historic theatre in Italy, while Kontogeorgiou, Bellou and Mikropoulos (2008) describe the exploration of 3-D simulated microscopic environments in an effort to allow students to experience being inside a quantum atom. In Virtual Big Beef Creek (Campbell, Collins, Hadaway, Hedley & Stoermer, 2002), a 3-D VE that recreates a marine and coastal environment to assist in the teaching of ocean science, learners can assume the roles of scientists to collect and analyse geo-scientific data or alternatively, take on characters representing creatures that inhabit the environment, which are variously able to walk over land, swim underwater or fly across the sky. In this way, the learners are able to explore first-hand the abilities and limitations of the various animals while simultaneously acquiring knowledge about the flora, fauna, ecosystem and ocean environment at large.

The ability to move freely around the 3-D VLE, view it from any position and manipulate objects within it has the potential to assist in the development of spatial knowledge of the real environment beyond what is possible through non 3-D alternatives, including those using photographic or video material or panoramic photographic technologies (eg, QuickTime VR— see Apple, 2008). This leads to the first learning affordance of 3-D VLEs:

Affordance 1: 3-D VLEs can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain.

One of the most important potential benefits of simulations occurs through the learner interacting with objects in the VE. Any knowledge domain in which the learner is expected to develop an understanding of entities exhibiting dynamic behaviours may be suited to simulations where the learner is able to construct a personal knowledge

representation and iteratively refine this representation as he or she undertakes exploration and experimentation in a manner consistent with cognitive constructivist learning theories (Jonassen, 1991; Piaget, 1973). For example, physics students are expected to understand how objects will respond to forces; exploring an environment that allows for specific forces to be applied to objects and for the resultant object behaviours to be observed and measured may assist in improving their conceptual understanding (Chee & Hooi, 2002). Three-dimensional technologies are well suited to such physical simulations because they enable the full physical behaviour of objects to be modelled, rather than restricting the motion and behaviour to two dimensions. Learning benefits over 2-D simulations will occur if the use of a 3-D VE similar to this leads to a 3-D conceptual model of the physical concepts rather than a simplified 2-D conceptual model and/or if learners stand to gain from viewing an object or setting from more than one vantage point (Bricken, 1990; Dede, Salzman & Loftin, 1996). Again, then, the spatial knowledge representation afforded by 3-D VEs provides the potential for learning benefits.

Simulations can also allow learners to practise skills or undertake embodied learning tasks, and this is particularly appropriate when the tasks involved are expensive, dangerous or risky to undertake in the real world. For example, 3-D VE-based simulations have been used to train nuclear power plant workers in Japan (Akiyoshi, Miwa & Nishida, 1996, as cited in Winn & Jackson, 1999), train astronauts on how to repair a space telescope (Moore, 1995; Psotka, 1995) and train forestry machine operators (Lapointe & Robert, 2000). Chen and Toh (2005) describe a driver education resource containing interactive 3-D simulations of driver education scenarios, and John (2007) surveys a range of Web3D-based tools that have been designed to support training for a variety of medical procedures. This leads to the second affordance of 3-D VLEs:

Affordance 2: 3-D VLEs can be used to facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world.

In some knowledge domains, the concepts to be learnt are abstract and do not correspond directly to material objects. The term 'microworld' is often used to describe simulations of abstract environments designed for concept formation (Rieber, 1992). Winn and Jackson (1999) suggest that VEs are 'most useful when they embody concepts and principles that are not normally accessible to the senses' (p. 7). They use the term 'reification' to describe the representation of phenomena that have no natural form. For example, they describe an environment that allows learners to control greenhouse gas emissions and view models that metaphorically represent the effects of global climate change. Ruzic (1999) also notes the potential for the use of metaphorical entities within VEs, suggesting that such environments incorporate two types of objects, 'tangible (sensory) objects called sensory transducers, and intangible, cognitive objects called cognitive transducers' (p. 189).

Other examples of 3-D microworlds for learning are portrayed by the following: Kaufmann, Schmalstieg and Wagner (2000) and Yeh and Nason (2004), who describe 3-D environments for developing learners' understanding of geometry; Bares, Zettlemoyer

and Lester (1998), who describe a 'CPU City' microworld used in the teaching of computer science; and Salzman, Dede, Loftin and Chen (1999), who describe three immersive environments that provide abstract spatial representations that allow learners to explore Newtonian mechanics, electrostatic forces and molecular bonding. The simulated radioactivity laboratory described by Crosier, Cobb and Wilson (2000) allows learners to carry out tasks and measure the results at the laboratory level, then zoom in and visualise what is happening at the atomic level. Furthermore, 3-D microworlds may be used to allow the learner to construct his or her own 3-D environment and/or objects as a way of articulating his or her spatial model or 'externalising' his or her understanding of particular abstract concepts (Winn, 2002). A number of 3-D concept mapping tools have been developed for such purposes, examples of which are Nelements (AYAR Software, 2007) and Topicscape (3D-Scape, 2008).

The aforementioned examples of 3-D microworlds and abstract simulations have at least one thing in common: the way in which they help the learner to understand the concepts within the target domain by capitalising on the first affordance of 3-D VLEs discussed earlier, namely their ability to support learning tasks leading to the formation of spatial knowledge representations.

Another potential learning benefit of simulations and microworlds is that they can be intrinsically motivating and engaging as a result of the high degree of personalisation that arises from the ability of the learner to make choices in attempting to achieve individual goals within the environment (Cordova & Lepper, 1996; Rieber, 2005). Game- and narrative-based approaches, when used in conjunction with 3-D VEs, can also contribute to learner motivation and engagement (Garris, Ahlers & Driskell, 2002; Mitchell & Savill-Smith, 2005). According to Csikszentmihalyi (1990), some activities can be so engaging that our mental focus is shifted away from our surroundings and from the day-to-day stresses in our lives, allowing us to focus entirely on the task. He uses the term 'flow' to describe the learner's experience in these situations. The high degree of fidelity and the natural interface of 3-D VEs may increase the likelihood that learners will experience this feeling of flow as they become psychologically immersed within the environment. This illustrates, then, the third learning affordance of 3-D VLEs:

Affordance 3: 3-D VLEs can be used to facilitate learning tasks that lead to increased intrinsic motivation and engagement.

3-D environments as interfaces to learning resources

A number of studies have found that learners can have difficulty navigating hypermedia environments, with the problems characterised by the 'lost in hyperspace' phenomenon (MacKnight, Dillon & Richardson, 1991) whereby users lose track of how they arrived at a node and have no clear model of the overall environment structure. The provision of an interface that allows easy navigation through the information, while maintaining a sense for the overall structure of the resources and the connections between ideas, is problematic. Three-dimensional environments offer transparency of

knowledge representation, which allows learners to approach concepts as ‘first-person, non-symbolic’ experiences, in contrast to most instances in which information is codified and represented as ‘third-person, symbolic’ experiences (Winn, 1993, cited in Dickey, 2005a). These applications attempt to capitalise on learners’ well-developed spatial cognitive abilities to assist them in navigating within the information space (Liang & Sedig, 2009). Card, Robertson and York’s (1996) description of the use of a 3-D environment as an interface for navigating through a complex information space and Robertson *et al*’s (2000) description of the use of a 3-D interface for task management on a PC are consistent with this idea. Applications such as these provide further examples of the first affordance mentioned earlier, ie, the ability of 3-D VLEs to facilitate learning tasks leading to spatial knowledge representation. The formation of a spatial cognitive model of the information space as a result of exploring an environment has the potential to boost exploration efficiency and conceptual understanding of the learning domain.

It can also be argued that there will be more effective real-world application of newly acquired knowledge and skills if the learning environment is modelled on the context in which the knowledge is expected to be applied. Specifically, because 3-D technologies can provide levels of visual or sensory realism and interactivity consistent with the real world, ideas learnt within a 3-D VE should be more readily recalled and applied within the corresponding real environment. This is a logical corollary to the idea that knowledge can be internally anchored to experience. Research carried out by Baddeley (1993) supports this idea by suggesting that facts learnt by divers under water are better recalled while diving than facts learnt on land. Ruzic (1999) emphasises the situated nature of learning in VEs, and consequently, the potential for application within similar real environments, stating that ‘The advantages of VR-based teleteaching are individualized, interactive and realistic learning that makes virtual reality a tool for apprenticeship training, providing a unique opportunity for situated learning’ (p. 188). Many other authors (eg, Bronack, Riedl & Tashner, 2005; Chittaro & Ranon, 2007; McLellan, 2004) have similarly noted the potential for 3-D VLEs to situate learning, drawing on the theoretical foundations laid down by Lave and Wenger (1991) and Brown, Collins and Duguid (1989).

This leads to the fourth learning affordance:

Affordance 4. 3-D VLEs can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualisation of learning.

3-D multi-user VLEs

Dede (1995) discussed the possibility of combining the capabilities of VEs with the capabilities of computer-mediated communication tools to promote collaborative learning within a distributed virtual space. Today’s multi-user, distributed 3-D environments, including MMOGs and virtual worlds, allow geographically dispersed users to explore an environment concurrently, with each represented by a surrogate persona or avatar visible to other users and with tools allowing text-based or audio communica-

tion. At a simple level, such environments can provide a vehicle for remote support by a teacher or facilitator as a learner undertakes learning tasks. However, they also have great potential as social learning and computer-supported collaborative learning tools (Edirisingha, Nie, Pluciennik & Young, 2009). According to social constructivist views of learning, conversation and discourse are the cornerstones of collaboration and social negotiation in learning (Jonassen, 1999; Lave & Wenger, 1991; Vygotsky, 1978). Communication within a simulated environment relevant to the ideas being discussed can provide a greater 'sense of place' than other text-based alternatives such as instant messaging, chat rooms and multi-user dungeons/dimensions (perhaps better known as 'MUDs'), and consequently, it can help foster greater closeness within the group and richer communication because of the ability to draw on spatial and non-verbal cues. If role-play strategies are used, it is likely that learners will more easily 'lose themselves' as they adopt their role and identify with their avatar because of the fidelity of the environment. This ability to self-define and take on alternate personae gives learners opportunities to adopt multiple perspectives, the importance of which is a key tenet of constructivist learning (Honebein, 1996; Jonassen, 1991, 1994), while the willed suspension of disbelief and emotional realism encourage them to engage in exploration, inquiry and risk taking (Dickey, 2005b).

Most importantly, multi-user 3-D environments can allow learners to carry out tasks together rather than just communicate. It is widely acknowledged that cooperative and collaborative learning strategies should involve activities and tasks that entail positive interdependence between participants or, in other words, require that each group member's efforts be indispensable for the success of the group in achieving its goals and that each member make a unique and valued contribution through his or her resources and/or role and task responsibilities (Johnson & Johnson, 1994; Johnson, Johnson & Holubec, 1993). Three-dimensional VEs that allow learners to engage simultaneously in shared tasks and/or produce joint artefacts by operating on the same objects in real time can pave the way for rich and truly collaborative experiences that foster positive interdependence within a learning group. For example, Mennecke, Hassall and Triplett (2008) report on how students undertake a scavenger hunt activity in SL, in which they co-experience and explore the virtual world as they embark on a mission to discover interesting places and practise basic SL skills. To complete the exercise, they must retrieve the relevant instructions, decipher the embedded hints and 'teleport' to the location of the item they are searching for. The activity requires students to work in teams, communicating and coordinating their activities and collaborating in the process. Successful completion is achieved when the team leader submits a note card containing details of the team's collaboration as outlined in the scavenger hunt instructions.

In another example, Jarmon, Traphagan and Mayrath (2008) tell of how students in a graduate-level communication course work together and in collaboration with architecture students at the same university. The communication and architecture students are tasked with creating a virtual presence in SL of two green, sustainable, urban housing designs, that are later physically implemented in a low-income neighbourhood

in Austin, Texas. Successful completion of the course assignments and projects is contingent on the students in both disciplines interacting extensively with educational and non-academic participants, both in real life and in the 3-D virtual world. Positive interdependence is also evident in that the communication students are reliant upon the domain knowledge and expertise of the architects, and vice versa.

These examples demonstrate the fifth learning affordance of 3-D VLEs:

Affordance 5: 3-D VLEs can be used to facilitate tasks that lead to richer and/or more effective collaborative learning than is possible with 2-D alternatives.

A model of learning in 3-D VLEs

Taking the results of the analysis in the previous section, along with the 10 distinguishing characteristics of 3-D VLEs identified earlier in the article, allows the initial model shown in Figure 1 to be used as the basis of the detailed model of learning in 3-D VLEs illustrated in Figure 2. This model presents an overall or big-picture snapshot of what authors are claiming/asserting and implying about 3-D VLEs, their characteristics and potential learning benefits, much of which calls for further investigation. It has the potential to contribute to the conceptualisation of a research agenda for learning in 3-D VEs; the next section presents a preliminary outline or 'skeleton' of such an agenda.

Towards a research agenda: conclusion and recommendations

This article has highlighted the unique characteristics of 3-D VLEs, as well as the potential learning benefits that stem from their affordances, based on an examination of applications described in the literature. Much of what has been published about the educational uses of 3-D technologies is largely 'show-and-tell', presenting only anecdotal evidence or personal impressions that cannot be usefully generalised beyond the local context. The continually increasing amount of time and resources being allocated to the development of 3-D games and virtual worlds by institutions and education systems worldwide, on the premise of improved learning outcomes, calls for a concerted and systematic effort by researchers to ascertain whether or not, and if so, how, the capabilities and features of 3-D VLEs can be exploited in pedagogically sound ways. Surprisingly little is known about the cognitive value of desktop 3-D graphics and VR (Chen, 2006; Lee & Wong, 2008), notwithstanding the fact that the core technologies supporting these innovations are not new and have seen many uses not only in education, but also in diverse areas of commerce, industry, entertainment and the military since the genesis of the multimedia PC in the early 1990s.

To move ahead, the model of learning in 3-D VLEs derived in this article (Figure 2) may be used as a basis for defining an agenda for further research into the design and use of such environments. First and foremost, future research needs to include empirical studies to establish the validity of the assumptions about 3-D VLEs that are implicit within the design of these environments and the associated learning tasks. Many claims that have been made about the benefits of 3-D VEs for education are couched in

a long line of assumptions about technological advancements in computer graphics and multimedia, each asserting progressively better ways of facilitating cognitive tasks that seem sensible and obvious at face value (Scaife & Rogers, 1996). It is arguable that the degree to which 3-D VLEs have the potential to provide learning advantages over non-3-D resources, in particular, is dependent on a number of underlying, general assumptions about cognition and learning in 3-D environments, along with assumptions about links or connections between the distinguishing characteristics of 3-D VLEs and the potential or anticipated learning benefits shown in Figure 2.

For instance, a general assumption that needs empirical exploration is the supposition that learners will trust their VE-based experiences sufficiently to modify their mental models of the simulated concepts, thereby correcting any misconceptions held. An

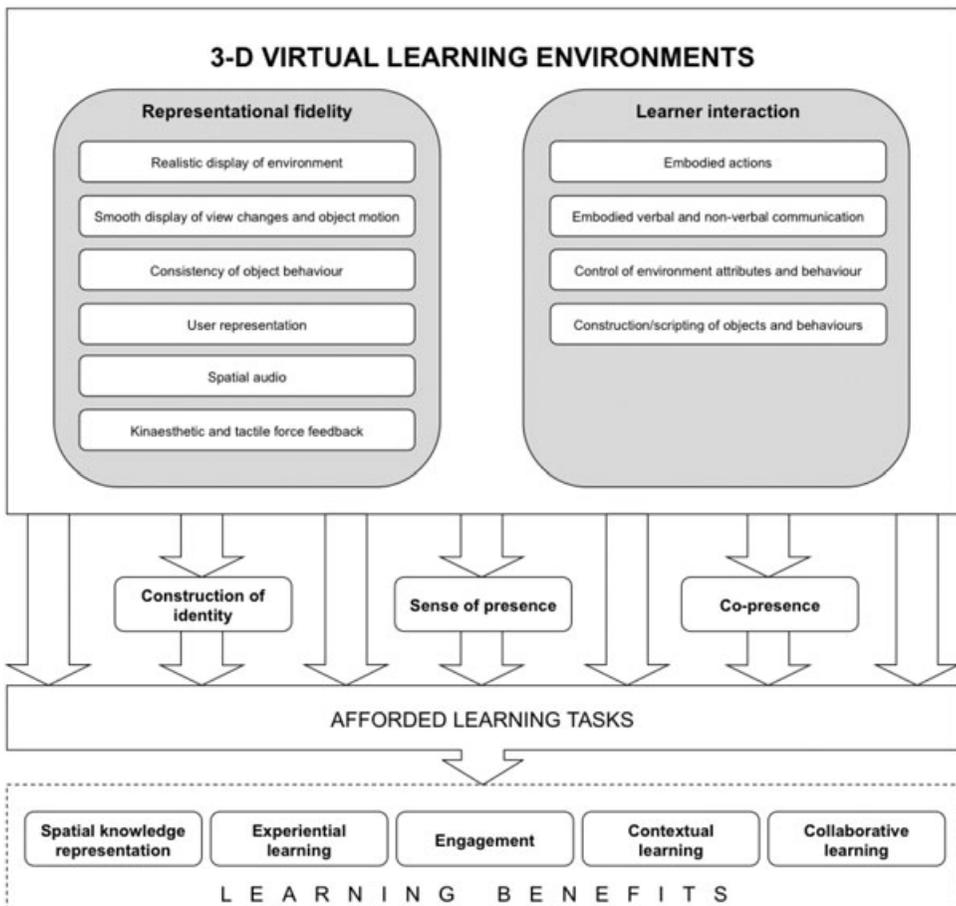


Figure 2: Elaborated model of learning in 3-D VLEs, incorporating unique characteristics and learning affordances

example of an assumption about the connections between characteristics of 3-D VLEs and their learning benefits may be seen in the notion that when factual information is learnt within a 3-D VLE, there will be a greater transfer of learning to the corresponding real environment. This notion hinges on an additional assumption, namely the intuition that the greater fidelity of a 3-D VLE leads to a greater sense of presence and consequently, greater transfer. A second example is the idea that the interactivity provided by 3-D VLEs will result in greater spatial learning than would occur when passively viewing an equivalent animation or video; a third is the assumption that a 3-D MUVE's representational fidelity and the embodied actions it facilitates will result in richer online identity construction and a greater sense of co-presence and that this in turn will bring about more effective collaborative learning.

In discussing the need for empirical exploration of the validity of the assumptions implicit within the design of 3-D VLEs, it is important to point out that we are not advocating studies that compare the learning benefits of equivalent 2-D and 3-D environments using contrived examples in inauthentic settings. Clark (1983, 1994a, b) has argued coherently against studies that look for a direct connection between a particular learning media or technology and learning on the basis that in such studies, it is not possible to separate the learning design from the media. We have argued in this article that 3-D VLEs afford certain learning tasks, or in other words, well-designed 3-D VLEs can enable learning tasks that are not possible or not as effective in 2-D environments. Comparisons between 2-D and 3-D environments that control the learning design across environments would be likely to only demonstrate the trivial fact that if the unique affordances of 3-D VLEs are not harnessed within the learning design, there will be minimal unique learning benefits.

Finally, realising the promise of 3-D VLEs to deliver enhanced learning and educational benefits necessitates applied research that derives design principles that will in turn inform the development of best practice. Such work is contingent on fulfilling the aforementioned need for empirical studies that establish the validity (or otherwise) of the basic assumptions about 3-D VLEs, and that link the unique characteristics of 3-D VLEs with the potential learning benefits. Currently, design and development efforts in this field are largely hit-and-miss, driven by intuition and 'common-sense' extrapolations rather than being solidly underpinned by research-informed models and frameworks. More work is needed to bring the virtual world/games development and education communities closer together (de Freitas, 2006), and researchers and practitioners must make time for awareness raising, dialogue and discussion about what works and why, and which combinations of pedagogic strategies and tools best target the desired outcomes. Teachers and learners require time for up-skilling and development, as well as guidance on how to plan and implement appropriate activities to use in conjunction with 3-D VLEs, including both those that are endogenous and exogenous to the virtual world or environment.

Table 2 summarises the proposed agenda and by way of illustration, lists some of the many possible research questions to be addressed and hypotheses to be tested within

Table 2: A roadmap for further research into 3-D virtual learning environments (VLEs)

Study type	Overarching goal/rationale	Examples of research questions to be addressed
Testing basic assumptions and linking characteristics to affordances	Return to 'first principles' by validating or refuting the basic, underlying assumptions implicit in the design and use of 3-D VLEs, and in particular determining and defining the relationships between the unique characteristics of 3-D VLEs, the intermediate outcomes (identity, presence, co-presence) and the anticipated learning benefits that arise from the tasks afforded by these environments.	<ul style="list-style-type: none"> • Will learners trust experiences in a 3-D VLE sufficiently to modify any misconceptions held? • Do realistic display, smooth view changes and embodied actions each contribute independently or together to spatial knowledge development, when compared to alternative static or animated images? • How important are the various aspects of the environment fidelity, such as visual realism and refresh rate, to the achievement of a sense of presence in a 3-D VLE? • Do the use of spatial audio and tactile feedback lead to the achievement of a greater sense of presence in a 3-D VLE? • Do the greater fidelity and sense of presence within a 3-D VLE lead to greater engagement and intrinsic motivation? • Do the greater fidelity and sense of presence within a 3-D VLE lead to improved contextualisation of learning, manifested through greater transfer to a corresponding real environment? • How do the use of and the fidelity of spatial audio and tactile feedback in 3-D VLEs contribute to the learner's development of spatial knowledge representations? • Do the facilitation of embodied actions and communication within a 3-D MUVE lead to a greater sense of co-presence? Does this, in turn, afford learning tasks that encourage richer and/or more effective collaborative learning than is possible with 2-D alternatives?
Establishing guidelines and best practice	Identify/derive rules and principles that will guide and inform the design and development of 3-D VLEs and associated learning tasks.	<ul style="list-style-type: none"> • What changes to accepted design principles from established theories (eg, cognitive load theory, dual coding theory, cognitive theory of multimedia learning), if any, are needed when instructional elements are presented within a 3-D VLE? • How can learning tasks to be carried out within a 3-D VLE be designed to meet specific, desired educational outcomes (eg, content knowledge in particular subject domains, generic skills such as teamwork and problem solving)? • What are the essential characteristics of learning tasks within a 3-D VLE that will make such tasks intrinsically motivating? • What are the essential characteristics of learning tasks within a 3-D VLE that will result in a high sense of presence? How important is suspension of disbelief to the achievement of both cognitive and affective learning goals?

each of the three aforementioned categories. It is worth noting that there is already an ongoing stream of research that attempts to address some of these questions; however, a more unified effort is needed to accurately target, validate and take advantage of the capabilities and features of 3-D VEs for learning, working from the ground up. Once the fundamental questions have been properly addressed, developers of 3-D VLEs and educators wishing to make use of these tools in their classrooms will have a firm basis for their design decisions. Even more importantly, when more is known about the aspects of such environments that are critical for learning, there will be a much greater likelihood that sound instructional design and pedagogy will prevail over the mere novelty of the technology. It is only then that the resources developed can truly move beyond simply impressing the learner with technological 'niftiness' or visual realism to actually facilitate effective learning.

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