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Creating and Retrieving Knowledge in 3D Virtual Worlds

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Abstract

This article provides a perspective on space as a means for experimental learning. Creating, exploring, and sharing spaces can be seen and used as learning activities. My discussion in this article focuses on various aspects of using virtual space for conveying understanding, expressing and sharing ideas, and presenting educational and research content. I ground the discussion on the results of several studies I conducted with colleagues on various educational and research activities in three-dimensional virtual worlds. This technology provides a unique set of features that can be used for resembling and optimizing functionalities of the real world. Such virtual worlds resemble the real world by being persistent, synchronous, multiuser, and providing three-dimensional representation of environments, users, and other objects. In addition, this technology augments the features resembled from the real world by functions that are difficult or impossible to implement in reality. Such functions include effortless space and time travel, enhanced interaction, resource and experience sharing, and tracking and retrieving activities. These affordances of the technology allow learners to co-construct their understanding through co-constructing the virtual space, interacting there with high immersion, and tracking their activities and knowledge for later retrieval. We explored the process of collaborative construction to understand if and how it contributes to learning. At the same time, we studied visualizations as the outcomes of this process to find a way for describing them and understanding what makes them work. In another set of studies, we explored the possibilities of virtual recording and virtual time travel. In educational context, such features become promising as they allow detailed analysis of activities and reflection. Overall, this article is a discussion of possibilities and challenges for creating

and retrieving knowledge in three-dimensional virtual worlds based on the results of exploratory studies.

1. Introduction

In this article, I discuss the role of 3D space and affordances of 3D Virtual Worlds (VWs) for facilitating collaborative creation and retrieval of knowledge. Knowledge resides in and is accessible from repositories. It may be stored not only in tangible artifacts, such as written instructions and databases, but also in activities, practices, relations between participants, and in their shared experiences. The former type of knowledge is known as explicit and the latter as tacit[1]. In a professional development in a given trade or education, the two types of knowledge are mutually dependent and mutually constituting[2]. Tacit knowledge is usually conveyed to explicit knowledge through narratives in addition to iterative training that create embodied experience through such activities. If knowledge is stored as activities that can be re-experienced, analyzed and reflected upon, it can be used for mastering high-level skills such as pattern recognition. The technology of 3D VWs has potential and, in some cases, affordances for conducting interactive activities that can simulate real-life experience, store, and retrieve them.

This technology has been extensively used for preserving cultural heritage and making the knowledge accessible by implementing virtual museums and reconstructions of artifacts and places[3]. To date, a large number of disciplines have been implemented in 3D VWs in both experimental and everyday teaching nature. Around 2009, it was estimated that about 300 higher education institutions had presence in Second Life alone[4]. Still, the full impact of as well as understanding of learning in virtual environments is relatively underdeveloped[5].

However, studies suggest that 3D visualization can improve learning significantly[6] and assist learners in relating theoretical knowledge to practice[7]. At the same time, a collection of static or even interactive objects and environments do not provide a solid enough representation of community knowledge. Learning communities may carry and communicate part of their knowledge, both

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[1] Polanyi, M. (1966)
[2] Nonaka, I. and Takeuchi, H. (1995)
[3] Styliani, S., Fotis, L., Kostas, K. and Petros, P. (2009)
[4] Salmon, G. and Hawkridge, D. (2009)
[5] Savin-Baden, M. (2013)
[6] Korakakis, G., Boudouvis, A., Palyvos, J. and Pavlatou, E. A. (2012)
[7] Behzadan, A. H. and Kamat, V. R. (2013)

tacit and explicit, through collaborative activities, practices, relations, and experiences. Such fluid ‘knowledge containers’ are difficult to capture and store in traditional repositories, but the knowledge they carry is essential for many high-skill professions. Drawing upon the work in activity theory[8], activity can be seen as a primary source of knowledge development and distribution. Therefore, visualizing and crystallizing activities are crucial for learning.

In this article, I discuss the process of collaborative construction and other activities in 3D space as means for visualizing knowledge, based on the results of empirical studies. Then, I focus on the possibilities for storing and retrieving traces of these ‘crystallized activities’ and knowledge they contain. I discuss our earlier explorative experience of crystallizing activities in 3D VWs in different ways, e.g., as traces of activities held in 3D constructions, as 3D constructions themselves, and as 3D virtual recordings. Further, I explore what knowledge can be created conducting activities in 3D virtual space, how it can be stored and retrieved, considering both educational potential of such knowledge and technological challenges and opportunities of this approach.

The goal of this article is to provide a different view on the notion of ‘crystallized activity’ as a container of knowledge created in a 3D space. In addition, it presents examples and a discussion of the new learning scenarios becoming available using this approach.

2. Background

2.1. Overview of 3D virtual worlds

Formal definitions are rare in the area of three-dimensional desktop virtual environments, since it is relatively new and complex[9]. The technology appeared on the interception between virtual reality and networked computers. There exist few terms to call the technology itself. These terms have overlapping meanings and are often used to describe the same phenomenon. Most commonly used terms include collaborative virtual environments (CVEs), Multi-user Virtual Environments (MUVEs), Desktop Virtual Reality (DVR), and Virtual Worlds (VWs). In this work, I will use the term three-dimensional Virtual Worlds (3D VWs), as the platforms I use for case studies chosen this term, stressing their global nature and the type of navigation interface.

[8] Leont'ev, A. N. (1981), Engeström, Y. (1999)
[9] Bell, M. W. (2008), Schmeil, A. and Eppler, M. J. (2009)

Based on several sources, 3D VWs can be defined as three dimensional, multiuser, synchronous, persistent environments, facilitated by networked computers[10]. It should be noted that three-dimensional interface is a relatively recent feature that has been applied to the VWs which existed long before it[11]. The technology discussed in this article should also be distinguished from highly immersive environments such as head-mounted displays[12] and immersive projection technology displays[13]. I consider the 3D VWs designed for (but not limited to) desktop. In such 3D VWs, users are represented by animated avatars and can interact using text-based chat, voice chat, and gestures. In addition, 3D technology allows interaction with various types of objects, including 3D objects and other media, such as text, graphics, sound, and video.

There are many application domains of 3D VWs, and their use has been growing rapidly in the first decade of the 21st century. Although entertainment remains one of the most successful application domains throughout the history of VWs[14], many platforms are created to be used for 'serious' purposes[15]. Education is often considered to be the main serious use of 3D VWs[16]. However, there are many others, such as training, research, commerce, and socialization. Developing quality specialized 3D VWs is expensive, but there are examples in the military and health care training. Examples of medical schools using VWs include virtual lectures, training interaction with patients, managing healthcare facilities, various visualizations, and collaborative tasks[17]. Four major areas of VWs healthcare applications are professional information sharing, clinical simulation, healthcare delivery, and research[18]. Examples of VWs used in military training include Tactical Iraqi and First Person Cultural Trainer[19]. Such environments are typically very expensive to develop, but attempt to create low-cost alternatives are starting to appear[20]. 3D VWs and other virtual reality technologies are becoming increasingly integrated to the military training practice[21].

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[10] Bell (2008), de Freitas, S. (2008b), Schmeil and Eppler (2009)
[11] Bartle, R. (2003)
[12] Holliman, N. S., Dodgson, N. A., Favalora, G. E. and Pockett, L. (2011)
[13] Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V. and Hart, J. C. (1992)
[14] Bartle (2003)
[15] Wrzesien, M. and Raya, M. A. (2010), de Freitas, S. (2008a), Messinger, P. R., Stroulia, E. and Lyons, K. (2008)
[16] de Freitas (2008b)
[17] Hansen, M. M. (2008)
[18] Holloway, D. (2012), Foronda, C., Godsall, L. and Trybulski, J. (2013)
[19] Johnson, W. L. (2009), Zielke, M. A. (2011), Surface, E. A., Dierdorff, E. C. and Watson, A. M. (2007)
[20] Prasolova-Førland, E., Fominykh, M., Darisiro, R. and Mørch, A. I. (2013)
[21] Lele, A. (2013)

2.2. Educational use of 3D virtual worlds

3D VWs have long been attracting attention of educators and researchers. This technology provides a unique set of features that can be used for educational purposes, such as low cost and high safety, three-dimensional representation of learners and objects, interaction in simulated contexts with high immersion[22] and a sense of presence[23].

Possibilities for synchronous communication and interaction allow using 3D VWs by various collaborative learning approaches[24]. In addition, possibilities for simulating environments on demand and for active collaborative work on the content allow applying situated learning[25] and project-based learning[26] approaches.

Constructivist approaches, such as problem-based learning, are also popular among the adopters of 3D VWs[27]. Social constructivism is often applied for learning in 3D VWs, as the technology allows learners to construct their understanding collaboratively[28].

Exploiting advantages of the content manipulation, 3D VWs can be used as cost-effective prototyping platforms to build and evaluate models or realistic simulations of existing or planned spaces[29]. A well-known example is prototyping a hospital Palomar Pomerado Health in Second Life before constructing it[30]. The virtual environment allowed all the stakeholders involved into the construction to explore the building in the way they would do in reality. Using the avatars, they could walk the corridors, offices, and open spaces of the virtual hospital test and experience how it feels. They could also do that collaboratively.

VWs can be well used as information visualization environments, immersing users and providing them with rich sensory experience[31]. In addition, VWs are used for educational simulations[32] and demonstrating complex concepts[33].

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[22] Cram, A., Hedberg, J. and Gosper, M. (2011)
[23] Mckerlich, R., Riis, M., Anderson, T. and Eastman, B. (2011), Dede, C. (2009)
[24] Lee, M. J. W. (2009)
[25] Hayes, E. R. (2006)
[26] Jarmon, L., Traphagan, T. and Mayrath, M. (2008)
[27] Bignell, S. and Parson, V. (2010)
[28] Molka-Danielsen, J. (2009), Coffman, T. and Klinger, M. B. (2007), Huang, H.-M., Rauch, U. and Liaw, S.-S. (2010)
[29] Minocha, S. and Reeves, A. J. (2010)
[30] Zensius, N. (2009)
[31] Chen, C. and Börner, K. (2005), Bowman, D. A., North, C., Chen, J., Polys, N. F., Pyla, P. S. and Yilmaz, U. (2003)
[32] Falconer, L. and Frutos-Perez, M. (2009)
[33] Youngblut, C. (1998), Dekker, G. A., Moreland, J. and van der Veen, J. (2011)

Despite the repeated positive conclusions, researchers often report that their studies have experimental nature. At the same time, many learning approaches are already used in 3D VWs, and even a new phenomenon "Virtual world pedagogy" is being discussed[34].

2.3. Collaborative work with 3D content

One of the major topics discussed in this article is creation of knowledge in 3D VWs by the process of collaborative visualization, an activity that is both a promising learning approach and well supported by the technology.

3D VWs have the possibility for supporting collaborative work with various types of content, as discussed in several studies[35]. Most 3D VWs allow advanced content manipulation, uploading, creating, and sharing 3D objects and other media, such as text, graphics, sound, and video. In this context, the term 'content' can be understood more widely than media objects. It can be "objects, places, activities" or any valuable information or experience[36].

Besides the possibilities for active and collaborative manipulation on the content, the technology allows storing, sharing, and exhibiting the content in a community repository as well as live presentation, discussion, and experience. Wide possibilities for conducting meetings, events, and performances extend the use cases for collaborative work on 3D content[37]. 3D VWs support creating and sharing content – the key features of social networking[38].

2.4. Virtual space as an educational environment

The design of educational environments in 3D VWs has long been and remains an important issue recognized by researchers, educators, and developers[39].

Using place metaphors in the design of educational 3D VWs is a common practice[40]. Virtual campus metaphor might be seen as one of the most ap-

[34] Dawley, L. (2009)
[35] Atkins, C. (2009), Hwang, J., Park, H., Cha, J. and Shin, B. (2008), van Nederveen, S. (2007), Arreguin, C. (2007), Perera, I., Allison, C., Nicoll, J. R., Sturgeon, T. and Miller, A. (2010)
[36] Bessière, K., Ellis, J. B. and Kellogg, W. A. (2009)
[37] Sant, T. (2009)
[38] Owen, M. L., Grant, L., Sayers, S. and Facer, K. (2006), Smith, R., Oblinger, D., Johnson, L. F. and Lomas, C. P. (2007)
[39] Minocha and Reeves (2010), Dede, C. (1996), Molka-Danielsen, J., Deutschmann, M. and Panichi, L. (2009)

propriate for an educational VW. However, there are many other metaphors that are used in different contexts, such as virtual museums, galleries and theatres[41], virtual laboratories and workshops[42], virtual libraries[43], and virtual health-care centers and hospitals[44].

The choice of the metaphor and its design is usually based on particular learning goals and on the role of the VW. In most cases, the design focuses not only on the appearance of the 3D environment, but on the functionality, tools, and features[45]. Educational environments are often created within bigger virtual worlds using their advantages but also being restricted by their limitations[46].

Recent research suggests that 3D VWs may provide a strong sense of space, place, and location[47]. In this research, it is held that a 3DVW is a ‘new kind of space’ sharing with the real world a visual topology that includes ownership and belonging, and is invested by the understanding of the participants as to what is appropriate in the community. Whereas *space* is the opportunity, as provided by the 3D virtual environment, it becomes a *place* of experienced reality when acting[48]. Similarly, the concept of presence in a VW can be seen as spatial immersion that is related to technology and sensory data and as social presence that is related to interaction and cognition[49]. The emerging place is constituted as a social process in the intersection of human behavior, experience, and the materiality of the space available. Social interaction and performance of activities in a virtual space are meaningful experiences that may allow creating a sense of place and create intention to return to the places in a VW[50]. VWs can provide users with location awareness or a sense of where they are both in terms of navigation in space and being in a place[51]. Human memory is closely tied to space that can act as a repository for memories and a trigger that brings them up[52].

A virtual space becomes a container of artifacts used by the visitors in their activities. This process is contributing to the creation of a place. VWs have

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[40] Prasolova-Førland, E. (2005), Gu, N., Williams, A. and Gül, L. F. (2007), Li, F. and Maher, M. L. (2000)
[41] Sant (2009)
[42] Dalgarno, B., Bishop, A. G., Adlong, W. and Bedgood, D. R. (2009)
[43] Hill, V. and Lee, H.-J. (2009)
[44] Boulos, M. N. K., Hetherington, L. and Wheeler, S. (2007)
[45] Prasolova-Førland (2005)
[46] de Freitas (2008b), Hendaoui, A., Limayem, M. and Thompson, C. W. (2008)
[47] Boellstorff, T. (2009), Thorpe, S. J. (2011)
[48] Harrison, S. and Dourish, P. (1996)
[49] Saunders, C., Rutkowski, A. F., Genuchten, M. V., Vogel, D. and Orrego, J. M. (2011)
[50] Goel, L., Johnson, N., Junglas, I. and Ives, B. (2013)
[51] Benford, S., Bowers, J., Fahlén, L. E., Mariani, J. and Rodden, T. (1994)
[52] Yates, F. A. (1966), Huxor, A. (2001)

higher flexibility in comparison to the real world, allowing a community build, modify, and preserve the space with the possibility accessing them from anywhere at any time. These features of the technology led to the idea of virtual places as crystallization of personal and group memories, constituting the memory of the community[53].

2.5. Activities in 3D virtual worlds

Activity is very closely related to experience, memory, and knowledge. The possibility for conducting rich interactive collaborative activities makes 3D VWs outstanding. Considering all the technical and other types of the technology limitations, the experience it may provide is closer to the reality than with other types of technologies. Such activity can be thought from the perspective of activity theory, that links the development of knowledge to action and the use of artifacts[54]. It is also related to the notions of community memory, communities of practice[55] and the theory behind organizational memory[56].

According to Wenger, continuous negotiation of meaning is the core of social learning and involves two processes: participation and reification. Participation is the "complex process that combines doing, talking, thinking, feeling, and belonging." Reification is the "process of giving form to our experience by producing objects that congeal this experience into thingness"[57]. The collection of such artifacts comprises the shared repertoire and history of the community. Walsh and Ungson propose that interpretations of the past can be embedded not only in systems and artifacts, but within individuals through the narratives they may convey. Organizational and community memory consists of mental and structural artifacts[58], but it can also be thought of as processes and representational states[59]. In addition, a community memory consists of histories and trajectories of its members expressed in narratives.

Considering the background presented above, learning process and knowledge creation can be described as activities and characterized by narratives, collaboration, and social constructivism. Narratives are used for the diagnosis of problems and as repositories of existing knowledge both tacit and ex-

[53] Prasolova-Førland, E. (2004)
[54] Leont'ev (1981), Engeström (1999)
[55] Wenger, E. (1998)
[56] Ackerman, M. S. and Halverson, C. (1998)
[57] Wenger (1998)
[58] Walsh, J. P. and Ungson, G. R. (1991)
[59] Ackerman and Halverson (1998)

plicit[60]. They also contain the tacit knowledge of a given domain or a field of practice, and provide a bridge between tacit and explicit knowledge[61]. Through collaborative activities and shared practices, knowledge may be created and distributed among the participants. The process of socialization may give the learners access to the episteme or underlying game of a discipline, the most difficult knowledge to access[62].

2.6. Capturing activities in 3D virtual worlds

3D VWs allow conducting various activities, and capturing such activities is a complex task from the technological point of view, as part of the information is usually lost. The most common methods for that include capturing activities in VWs as screen shots, keeping chat logs, social tagging, and keeping track of people met and virtual places visited[63]. Activities in 3D VWs are also often recorded as 'flat' 2D video. This method usually provides a better overview of the activity, but still it eliminates many advantages of the technology, such as immersion, possibility for collaborative work or for further developing the 'crystallized activities', except for commenting and annotating them. This approach is used in Machinima – collaborative film making using screen capture in 3D VW and games[64].

The need for recording activities in 3D environments keeping the immersive context was acknowledged as early as in the late 90s, e.g. by developers of CAVE and MASSIVE systems. MASSIVE-3 supported a mechanism that allowed "real-time virtual environments to be linked to recordings of prior virtual environments so that the two appear to be overlaid"[65]. CAVE Research Network soft system had an application which supported recording of an avatar's gestures and audio together with a surrounding space[66]. Another example is the system called Asynchronous Virtual Classroom that allowed watching a video image of a lecture and to control it, while software agents were playing some of the dis-

[60] Polanyi (1966)
[61] Linde, C. (2001)
[62] Entwistle, N. (2005)
[63] Neustaedter, C. and Fedorovskaya, E. (2009)
[64] Barwell, G., Moore, C. and Walker, R. (2011)
[65] Greenhalgh, C., Flintham, M., Purbrick, J. and Benford, S. (2002)
[66] Leigh, J., Ali, M. D., Bailey, S., Banerjee, A., Banerjee, P., Curry, K., Curtis, J., Dech, F., Dodds, B., Foster, I., Fraser, S., Ganeshan, K., Glen, D., Grossman, R., Heil, Y., Hicks, J., Hudson, A. D., Imai, T., Khan, M. A., Kapoor, A., Kenyon, R. V., Park, K., Parod, B., Rajlich, P. J., Rasmussen, M., Rawlings, M., Robertson, D., Thongrong, S., Stein, R. J., Tuecke, S., Wallach, H., Wong, H. Y. and Wheless, G. (1999)

played participants and created a presence effect[67]. Later, Networked Virtual Environment Collaboration Trans-Oceanic Research project developed three approaches to support annotations for asynchronous collaboration in virtual reality, including a tool that allows attaching 3D virtual reality recordings to objects, an email system for virtual reality, and a streaming recorder to record all transactions that occur in a collaborative session[68]. More recently, an Event Recorder feature was implemented (however, not developed further) within the Project Wonderland[69]. It implements recording and playback of the 'events' caused by activities of users or agents in such a way that during playback a user is able to view the activities that those events caused.

All mentioned projects were contributing towards developing technological solutions for capturing and retrieving activities in 3D VWs or other similar environments. However, there is a clear possibility for improvement, as the potential of 3D spaces for community memory repositories was not yet realized.

3. Educational visualizations in 3D virtual worlds

We conducted three case studies on using 3D VWs for educational visualizations with colleagues at the Norwegian University of Science and Technology. All three studies were conducted within Cooperation Technology course. The goals of these studies were to explore the educational visualization as a teaching method and to explore the affordances of 3D VWs for capturing learning activities and storing them as part of community memory.

3.1. Case studies on educational visualizations in 3D virtual worlds

In this section, I discuss the results of three exploratory case studies conducted within Cooperation Technology undergraduate course in 2009, 2010, and 2011. In all three studies, we used the same environment and gave similar tasks to the students. However, each time we improved both the environment and the learning approach, based on the student feedback. We collected various types of qualitative and quantitative data from the log of the VW and from the student feedback. In addition, we took the anthropological approach, being constantly with the students in the VW, observing the processes of negotiation and construction.

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[67] Matsuura, K., Ogata, H. and Yano, Y. (1999)
[68] Imai, T., Qiu, Z., Behara, S., Tachi, S., Aoyama, T., Johnson, A. and Leigh, J. (2000)
[69] later, Open Wonderland™, http://openwonderland.org/

The teaching method we applied[70] is based on *constructionism* – an educational philosophy which implies that learning is more effective through the design and building of personally meaningful artifacts than consuming information alone[71]. In this perspective, the knowledge is constructed through an individual cognitive effort that is applied to the creation of a virtual artifact in 3D space or the space itself. Constructionism is related to the *social constructivist* approach, which proposes that learners co-construct their understanding together with their peers[72]. Knowledge and meaning in this perspective are collaboratively constructed through social processes and activities, based on previous experiences. The participants were trying to construct a common understanding to materialize it in the form of 3D space. In other words, they had a certain meaningful 'place' in mind and tried to construct a 'space' that can accommodate it.

In addition, we applied role playing which is a widely used and effective learning and teaching method. It implies an active behavior in accordance with a specific role[73]. We considered a student group a subject within a learning community. The results of activities performed by students are seen as artifacts and reification of experience[74] that is shared with other community members, e.g. future generations of students. In the following, I present the details of the studies in more detail.

In the 2009 study, six groups (3–4 students in each) were asked to build a visualization representing one of the research areas or a course taught at the university in the period of six weeks. The students were asked to consider how their constructions could be used in educational activities on the virtual campus and for promotion of the university. The resultant constructions were presented to the international audience at a joint session (Fig. 1). The visitors were guided through the building sites and asked to give their comments and feedback to the projects[75].

[70] Fominykh, M. and Prasolova-Førland, E. (2012)
[71] Bessière, Ellis and Kellogg (2009), Papert, S. and Harel, I. (1991)
[72] Vygotsky, L. S. (1978)
[73] McSharry, G. and Jones, S. (2000), Craciun, D. (2010)
[74] Wenger (1998)
[75] Prasolova-Førland, E., Fominykh, M. and Wyeld, T. G. (2010)

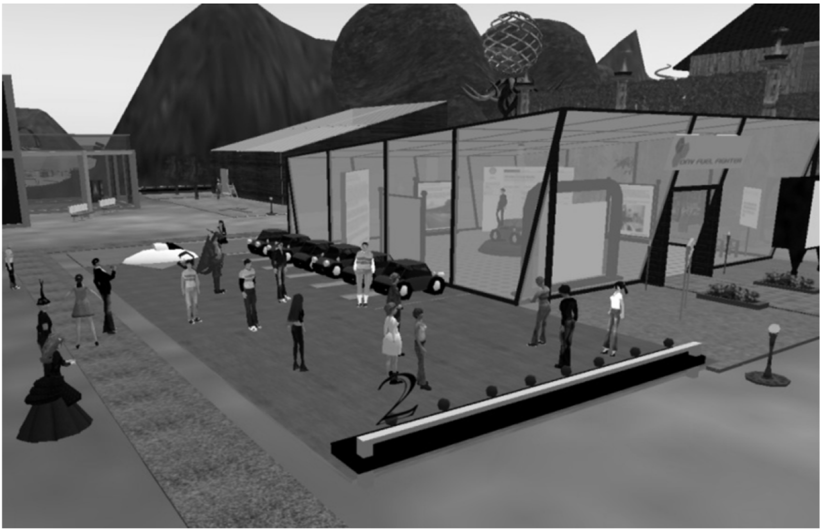

Figure 1. Student visualization project Fuel Fighter, 2009

The study in 2010 was conducted with 25 students in seven groups, 2–4 students in each. Each group was asked to build a visualization representing a research project in the period of one month and present it at a joint session by role-playing (Fig. 2). The joint session was extended by two virtual seminars on related topics led by invited experts[76].

[76] Fominykh, M. and Prasolova-Førland, E. (2011)

Figure 2. Student visualization project Solar Skin, 2010

In 2011, the study was conducted with 37 students in 10 groups, 3–4 students in each. The students were asked to build an educational module representing a major curriculum topic and present it at a joint session by role-playing. For example, one of the student groups visualized the concept of 'awareness' by constructing two remote laboratories that were full of elements exemplifying the concept. The activity conducted by the students was a role play in which the labs were working on a joint project and an accident occurred in one of them (Fig. 3). The second lab could take appropriate actions thanks to awareness mechanisms. Towards the end of the construction process, the groups received evaluations from students invited from the University of Hawaii at Manoa. After the role-playing session, each group evaluated two other constructions[77].

Figure 3. Student visualization project Awareness Lab, 2011

3.2. Supporting student visualization projects with Virtual Gallery

The Virtual Gallery (VG) was intended to assist constructing, presenting, and storing student 3D visualization projects in a shared repository and designed based on the results of a case study we conducted in 2009[78]. A library of pre-made 3D objects, scripts, and textures could allow concentrating more on the

[77] Fominykh, M., Prasolova-Førland, E. and Divitini, M. (2012)
[78] Prasolova-Førland, Fominykh and Wyeld (2010)

creativity instead of technical details. In addition, student 3D visualizations occupied considerable amount of space in our virtual campus in Second Life and there was a need for better storage solutions.

The VG was implemented, including a realistically reconstructed building (modeled after an existing student activity house on campus), a gallery for storing and presenting 3D constructions, and a library of pre-made 3D objects, scripts, textures, and links to other resources and virtual places (Fig. 4).

In two other studies in 2010[79] and 2011[80], we collected student feedback on their experience of using VG and its functions. The students were constructing 3D visualizations which were later stored in the VG.

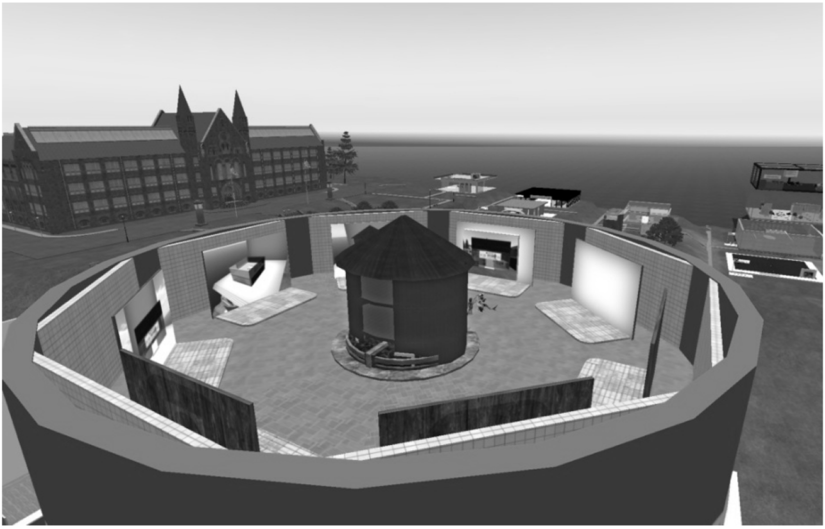

Figure 4. Virtual Gallery

3.3. Sharing visualization projects across communities in Virtual Research Arena

We studied further the possibilities of 3D VWs for educational visualizations and supporting learning communities that can form around them. We developed a framework, Virtual Research Arena (VRA), for creating awareness about educational and research activities, promoting cross-fertilization between different

[79] Fominykh and Prasolova-Førland (2011)
[80] Fominykh, Prasolova-Førland and Divitini (2012)

environments and engaging the public[81] that was later implemented as a prototype in Second Life. We formed a set of requirements for the VRA on three levels.

First, it should support collaborative work on 3D content, i.e. creating it, storing, and presenting. This function was made available through the VG which was integrated into the VRA. Second, it should provide appropriate atmosphere, tools, and facilities for the community activities. VRA should be a place, where students and researchers can visualize ideas and share them. It should accumulate 'reifications' or traces of community activities over time, thus becoming a community repository. Such a repository would be in many ways different from a 'traditional' one due to its fluid and tacit nature, reflecting the nature of the learning communities behind.

VRA functions as a virtual extension of the Norwegian Science Fair festival where research projects are presented to the public in a set of pavilions. A city landmark – King Olav Tower – was reconstructed on the virtual 'central square' that served as a venue for the fair in reality, to create an authentic atmosphere and a meeting place for the local and international online visitors. The virtual science fair exhibited eight research projects and a number of student projects during the live event. Some of the VRA visualizations were later used for holding project meetings and presentations, enriching 3D constructions with activity traces (Figure 5).

While the physical pavilions at the fair were deconstructed at the end of the event after two days, the virtual pavilions and the student constructions with activities traces have been preserved becoming a community repository. The feedback collected in a case study in 2010[82] showed that most of the students and visitors acknowledged the potential of 3D VWs and places like the VRA for supporting social networks and collaboration among various groups of participants as well as the importance of preserving their own constructions as a part of the VRA and the community.

[81] Fominykh and Prasolova-Førland (2011)
[82] Fominykh and Prasolova-Førland (2011)

Figure 5. Virtual Research Arena

4. Virtual recording in a 3D virtual world

Several attempts have been made to capture and activities in 3D space, as discussed earlier in section “Capturing activities in 3D virtual worlds”. In this section, I would like to present a prototype designed on a new platform vAcademia[83] that allows capturing activities in a 3D space, storing them, editing, and retrieving for analysis and secondary recording. vAcademia is a 3D VW that is designed for education. Its most distinctive feature is 3D recording, which allows capturing everything in a given location in the VW in process, including synchronized positions of the objects, appearance and movement of the avatars, media materials displayed, text and voice chat messages[84]. Similar functionalities were realized earlier in few VWs or desktop virtual reality systems. However, 3D recording was never developed into a convenient tool and never adopted for specific use as in vAcademia. In addition, no convenient tools for working with the resultant recordings were developed.

3D recording of classes allows getting a new type of learning content and involving students in new types of activities. A user can attend and work at a recorded class, not just view it as a spectator. In addition, any recorded classes can be attended by a group of users. A new group can work within a recorded

[83] http://vacademia.com/

[84] Morozov, M., Gerasimov, A., Fominykh, M. and Smorkalov, A. (2013)

class and record it again, but with their participation. Thus, there is an opportunity to build up content of recorded classes and layer realities on top of each other.

From the user point of view, 3D recording control is very similar to the regular video player. A 3D recording can be fast-forwarded and rewound, paused, and played again from any point of time. A replayed 3D recording looks exactly like a real class. Of cause, the recorded avatars will always act the way they were recorded. However, it is possible to use all the functionality of the VW inside a recording. Moreover, a replayed 3D recording can be recorded again together with new actions. In such a way, new recordings and new content can be created based on the same original event.

Considering the fact that such features of the vAcademia platform are useful for capturing traces of activities, storing and modifying them, we selected this platform for continuing this line of research.

4.1. Training medical personnel in vAcademia

The prototype implements a training environment for medical center managers. It is based on a typical scenario – answering phone calls. The basic training session is intended for a single user (Fig. 6). The trainee answers a call from a potential client (pre-recorded voice). Three options written in text are offered by an assisting bot. The trainee reads options and chooses one. If the option is correct, the trainee needs to say it (to continue the phone conversation). If not, the assistant advises to choose another one.

Figure 6. vAcademia training session

The prototype was evaluated with 44 managers over four months within the medical center it was designed for. The participants had no previous knowledge on the 3D VW technology (including vAcademia), but were provided with written user manuals. The observers recorded the first training attempt of each participant, then 6-8 attempts were allowed to improve the skill (using hints), and finally another control attempt was recorded (without hints). The results were evaluated by the experts. Particular attention was paid the correctness of the phrases, intonations, and the number of mistakes. An attempt was considered passed if a participant makes not more than two mistakes and pronounces all the phrases correctly. The results demonstrate that 20% of the trainees achieved the acceptable result in the first attempt, and 57% did it on the control attempt.

4.2. Using 3D recording for reflection and deeper learning in vAcademia

Even though the training session was designed for a single user, it can be recorded, stored, and revisited afterwards. The pauses in the conversation when the trainee is reading answer options are removed, and the recording would appear as a natural conversation. For example, the assistant can help in the first trial, but not in the second one. The resultant 3D recordings can be revisited by the same trainee (see Fig. 7) to analyze the performance and note places that can be improved or they can be revisited by the trainee and a mentor for more detailed analysis.

Meeting yourself-from-the-past (or even several selves) is an unusual experience. Observing own actions, while acting in the same space and having the same virtual representation, can be a strong trigger for reflection and self-assessment. Such experience goes much further than watching yourself in a video that captures you from a single point of view and that is separated from the observer. It goes further than just having an avatar in 3D space, as it represents a user in a different, a virtual reality.

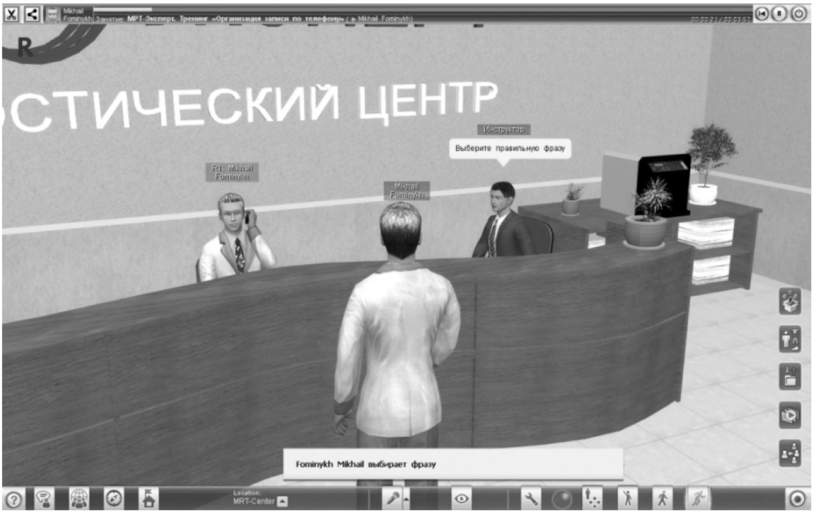

Figure 7. Attending a recorded training session in vAcademia

An important part of this type of training is the development of professional sensitivity of the learners and their understanding of care. This includes high-level skills such as "looking behind the words" of the patients, since patients often are unclear of what their problem is, or do not want to state their problem[85]. The possibilities of practicing a scenario (with some variations) and having multiple reifications of the crystallized actions-in-space can facilitate training of such high-level skills. The notion of care is also complicated since it challenges the learner's preconceptions with the "messy realities of practice"[86]. This change in perspective represents a threshold concept – a troublesome knowledge[87].

More generally, if using such training sessions regularly, it is possible to build a database of training 3D recordings. This would allow individual workers to track their performance, coming back to their actions-in-space, and the company – to have multiple examples (best and worst cases). It would provide an opportunity to identify what aspects of the learning outcomes are the most difficult to arrive at. This insight could again be fed into a redesign of courses and training programs. 3D recordings can be modified and annotated by experts – inserting additional actions in the same space, for example including theoretical explanations.

[85] Clouder, L. (2005)
[86] Barnitt, R. (1998)
[87] Meyer, J. H. F. and Land, R. (2003)

5. Discussion

Crystallizing activities in 3D VWs can be seen as an affordance of space and time simulated with this technology. It can be done differently from the technological point of view, capturing modified space that contains traces of past activities conducted in the space or capturing action-in-space that contains the space together with the activity that gives meaning it and adding the time dimension. In both cases, virtual space plays the role of a raw material to be modified to contain activities.

The use of 3D VWs as a means for creating and retrieving knowledge may benefit educational process considerably. As demonstrated by the studies presented earlier in this article, this technology provides affordances for conducting complex educational activities, mirroring them from the real life (such as virtual seminars) and enhancing with tasks that are not possible in reality (such as creating visualizations of abstract concepts). These results are confirmed by multiple studies that are summarized in section "Educational use of 3D virtual worlds". However, not much research has been done on trying to capture such educational activities and using them afterwards. The work presented in this article provides an attempt to address this.

Immersion into a well-designed virtual environment in itself may improve understanding of the structure and the complexity of a certain topic, area, or model. However, getting access to activities that are (or were) conducted in such an environment can help grasping the features of the space, improve the sense of place, and simplify the access to the traces of knowledge. This can allow capturing and recovering tacit knowledge, for example as repeated experience or narratives. Narratives prove bridges between tacit and explicit knowledge, while at the same time representing the collective history of a community. The usefulness of narratives increases when they are stored as crystallized activities. Enactment and participation, complemented with narratives, visualize certain aspects of the knowledge of a discipline or a profession, aspects that are more difficult to access through traditional training and learning facilities.

Following the Wenger's social learning process[88], capturing 'participation' as crystallized activities can be seen as 'reification'. At the same time, if an activity is crystallized in a 3D VW, it contains the traces of the original activity. An activity can be crystallized either as modified space (see examples in section "Educational visualizations in 3D virtual worlds") or as action-in-space (see examples in section "Virtual recording in a 3D virtual world"). Recovering

[88] Wenger (1998)

knowledge from activities crystallized in any of these ways would allow multiple reifications.

In an earlier work, we refer to this difference in capturing activities as the scale quality from explicit to implicit[89]. This quality describes to what extent a crystallized activity and its components can be experienced in the same way as a live activity.

Crystallizing an activity supplies it with qualities of content (virtual space, objects, and artifacts), making the transformation of some of the tacit knowledge it contains to explicit easier. For example, in educational visualization studies presented earlier in this article, the collaborative activities of negotiating the meaning, discussing ways of visualizing it, trying and failing are crystallized as tangible artifacts – virtual environments with objects and spaces. This allows activities to be operated like any other content, as we did with sharing them at the VRA. However, in order to make the best possible use of crystallized activities, they should be made active again. This challenge can be addressed in different ways, for example technologically by further developing the 3D recording feature. It can also be addressed methodologically by developing approaches for retrieving knowledge from crystallized activities.

Traces of activities can be made active by performing new or same activities in spaces that already contain crystallized activities, for example making a science project visualization 'active' again by performing a role play / seminar in the corresponding construction. 3D recordings are becoming active if someone visits them, but the method for extracting knowledge from them can be improved too.

When thinking of crystallized activities as pieces of content, they can also be seen as elements of knowledge. Crystallized activities may contain both explicit and tacit types of knowledge. Explicit knowledge is usually contained in a particular artifact that is a part of a virtual space, while tacit knowledge can be associated with the whole activity that is crystallized. This means that all the objects of the virtual environment are important to retrieve the tacit knowledge that resides in a crystallized activity.

The qualities of content acquired by the activities when they are crystallized in a 3D VW allow automating the process of knowledge retrieval. A crystallized activity can then be seen as a container of numerous elements (such as avatars, 3D objects, communication streams, and media contents). Automation of the analysis of such data and retrieving valuable information from a crystallized activity is a challenge. The difficulty lies in retrieving the knowledge

[89] Fominykh, M., Prasolova-Førland, E., Hokstad, L. M. and Morozov, M. (2014)

that resides in activity, but not necessarily in the objects or discrete elements. Automatic analysis of such elements may not reach externalization of tacit knowledge that resides in the crystallized activities, but still provide valuable auxiliary information about the conducted activities (e.g., for assessment, awareness, or recommendations). This task is challenging, as many types of data need to be analyzed and calibrated. For example, a certain activity may contain movements or gestures that matter and another one – phrases and intonations. In the former activity, the data to be analyzed will include distances, angles, and seconds. In the latter – number of words, types of phrases, and intonations.

5.1. Activities crystallized as modified space

In the case of activity traces crystallized in modified space, the process of reifications is more implicit and more dependent on the interpretation of those who access them. The educational use of the activities crystallized in this way may vary. For example, a gallery of 3D constructions that represent a topic of topics can be created to contain the meaning invested into them by the authors. A more indicative example is the traces of enactments or role playing captured as decorations, scripts, and artifacts used. Such objects can tell much about the play that was help in the environment or they can be used again for another play or related activity. Another example is a virtual place that holds regular activities, such as seminars, discussions, or training sessions. It may capture the traces of these activities in the design of the space (arrangement of objects and open spaces), artifacts created (minutes of meetings or other results of collaborative work), or scenarios developed over time (scripts or activity/working procedures). Such traces of activities can be used as a history of a learning community or a community memory.

Sharing 3D visualizations in the VRA (presented earlier) received a positive feedback. Most of the groups stressed the importance of studying previous students' constructions to have inspiration. Some of the groups stated also that they get additional motivation from being able to exhibit their construction for other people. Realistic buildings reconstructed in the virtual environment around the student visualization playground were recognized as supporting community and providing a sense of place[90]. Many participating students appreciated the sense of a familiar place that they experience when arriving to and working in the virtual space. At the same time, they wished the constructions of

[90] See more about the difference between sense of place and immersion in a virtual space in section "Virtual space as an educational environment"

the environment to be more functional, appreciating the tools and materials available at the VG. Familiar buildings created certain 'focal points' and a sense of place for both local community members and visiting students or researchers at the VRA, which was acknowledged as an important factor for sustaining the learning community.

Many participants have also stressed the importance of preserving their visualizations consequently each year, constituting a history of the learning community. The most popular reason given for this argument was inability to realize the potential of a learning community to the full extent within a short period (one semester). A gallery of crystallized activities provided a bridge between generations of students and constituted a learning community repository.

5.2. Activities crystallized as actions-in-space

In the case of activity traces crystallized as action-in-space, the process of reification is more explicit, but allows detailed analysis and reflection. The educational use of such activities is different significantly. From the methodological point of view, two formats can be identified. The first format is visiting a 3D recording, and the second is creating a new 3D recording while conducting activities being inside one.

The first format – visiting a 3D recording is similar to watching a video-recorded lecture or a webinar. However, a 3D recording can be watched being immersed into the virtual space. It can be visited by a group of learners who can actively work inside. All the interaction can be observed in the same way as in the live class. The only limitation is that the recorded avatars and objects cannot respond to the interaction of the live participants[91].

Re-visiting an activity crystallized as action-in-space (using 3D virtual recording) allows a great range of behaviors and responses. The main advantage of this way of capturing is the possibility to re-enter the activity and observe it from inside or re-experience it. All the actions of the participants (e.g., navigation, conversations, and space modification) and other changes that happen in the environment and influence the participants causing certain reactions (e.g., scenario flow or events) can be analyzed in detail. This method can enhance the students' experience greatly, as they are able to review and improve their skills.

The second format – creating a new 3D recording being inside one – is even more different and promising for education. A group of learners can enhance a 3D-recorded activity by visiting it and recording over again. As a result,

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[91] Morozov, Gerasimov, Fominykh and Smorkalov (2013)

another 3D recording will be created to contain new activities overlaid the ones of the original activity. New actions (e.g., analysis, discussions, questions, and comments) constitute another layer of 3D recording. New media materials and new virtual 3D objects can be used. All new details can be crystallized together with the original ones, in the same virtual space and in the same context.

An additional use case for the second format is editing the original activity. It is possible to fast-forward a 3D recording through the places that should be skipped. Alternatively, the teacher can pause the original 3D recording and add some missing material and objects or discuss a particular part with the students. Some parts of the original 3D recording can be replaced. The new layer of the crystallized activity (that may contain new materials) is synchronized with the original layer. It can be especially useful in the cases when a certain activity has to be repeated frequently. For example, educators can create a template of a class (containing both 3D virtual space and activity), but perform live discussions with each group of students, retrieving some of the knowledge crystallized in the template, and avoiding unnecessary duplication.

6. Conclusions

In this article, I discuss the affordances of 3D VWs for capturing and retrieving knowledge as crystallized activities. These affordances open for a wide range of potential usage areas, especially in the area of education, such as in serious games for corporate training, medical and emergency training and even military training, where activity (e.g., role playing) is a central component. 3D VWs can be used not only as virtual spaces for enactment, but also as a place for accessing traces of past activities to be enacted or collaborated into knowledge. Even though, many challenges of this approach were identified in the studies, it is promising and has to be developed further.

References

Ackerman, Mark S., and Halverson, Christine (1998): Considering an organization's memory, *ACM Conference on Computer Supported Cooperative Work (CSCW)*, Seattle, WA, USA.

Arreguin, Cathy (2007): *Reports from the Field: Second Life Community Convention 2007 Education Track Summary*, Global Kids, New York, USA.

Atkins, Clare (2009): "Virtual Experience: Observations on Second Life", in: Maryam Purvis and Bastin Savarimuthu, eds. (2009): *Computer-Mediated Social Networking*, Berlin / Heidelberg: Springer: 7–17.

Barnitt, Rosemary (1998): "The Virtuous Therapist", in: Jennifer Creek, ed. (1998): *Occupational Therapy: New Perspectives*, London, UK: Whurr Publishers: 77–98.

Bartle, Richard (2003): *Designing Virtual Worlds*. NJ, USA: New Riders.

Barwell, Graham, Moore, Chris, and Walker, Ruth (2011): "Marking machinima: A case study in assessing student use of a Web 2.0 technology", Vol. 27, *Australasian Journal of Educational Technology*: 765–780.

Behzadan, Amir H., and Kamat, Vineet R. (2013): "Enabling discovery-based learning in construction using telepresent augmented reality", Vol. 33, *Automation in Construction*: 3–10.

Bell, Mark W. (2008): "Toward a Definition of "Virtual Worlds"", Vol. 1, *Journal of Virtual Worlds Research*: 1–5.

Benford, S., Bowers, J., Fahlén, L. E., Mariani, J., and Rodden, T. (1994): "Supporting Cooperative Work in Virtual Environments", Vol. 37, *The Computer Journal*: 653–668.

Bessière, Katherine, Ellis, Jason B., and Kellogg, Wendy A. (2009): Acquiring a professional "second life": problems and prospects for the use of virtual worlds in business, *27th CHI International Conference extended abstracts on Human factors in computing systems*, Boston, MA, USA.

Bignell, Simon, and Parson, Vanessa (2010): *A guide to using problem-based learning in Second Life*, University of Derby, Derby, UK.

Boellstorff, Tom (2009): *Coming of Age in Second Life: An Anthropologist Explores the Virtually Human*. Princeton, NJ: Princeton University Press.

Boulos, Maged N. Kamel, Hetherington, Lee, and Wheeler, Steve (2007): "Second Life: an overview of the potential of 3-D virtual worlds in medical and health education", Vol. 24, *Health Information & Libraries*: 233–245.

Bowman, Doug A., North, Chris, Chen, Jian, Polys, Nicholas F., Pyla, Pardha S., and Yilmaz, Umur (2003): Information-rich virtual environments: theory, tools, and research agenda, *10th symposium on Virtual reality software and technology (VRST)*, October 1–3, Toonaka, Japan.

Chen, Chaomei, and Börner, Katy (2005): "From spatial proximity to semantic coherence: a quantitative approach to the study of group dynamics in collaborative virtual environments", Vol. 14, *Presence: Teleoperators and Virtual Environments (Special Issue on Collaborative Information Visualization Environments)*: 81–103.

Clouder, Lynn (2005): "Caring as a 'threshold concept': Transforming students in higher education into health (care) professionals", Vol. 10, *Teaching in Higher Education*: 505–517.

Coffman, Teresa, and Klinger, Mary Beth (2007): "Utilizing Virtual Worlds in Education: The Implications for Practice", Vol. 2, *International Journal of Human and Social Sciences*: 29–33.

Craciun, Dana (2010): "Role – playing as a Creative Method in Science Education", Vol. 1, *Journal of Science and Arts*: 175–182.

Cram, Andrew, Hedberg, John, and Gosper, Maree (2011): Beyond Immersion – Meaningful Involvement in Virtual Worlds, *2nd Global Conference on Learning and Technology (Global Learn Asia Pacific)*, March 28–April 1, Melbourne, Australia.

Cruz-Neira, Carolina, Sandin, Daniel J., DeFanti, Thomas A., Kenyon, Robert V., and Hart, John C. (1992): "The CAVE: audio visual experience automatic virtual environment", Vol. 35, *Commun. ACM*: 64–72.

Dalgarno, Barney, Bishop, Andrea G., Adlong, William, and Bedgood, Danny R. (2009): "Effectiveness of a Virtual Laboratory as a preparatory resource for Distance Education chemistry students", Vol. 53, *Computers & Education*: 853–865.

Dawley, Lisa (2009): "Social network knowledge construction: emerging virtual world pedagogy", Vol. 17, *On the Horizon*: 109–121.

de Freitas, Sara (2008a): *Emerging trends in serious games and virtual worlds*, Becta, Coventry, UK.

de Freitas, Sara (2008b): *Serious Virtual Worlds report*, Joint Information Systems Committee, Bristol / London, UK.

Dede, Chris (1996): "The evolution of constructivist learning environments: Immersion in distributed, virtual worlds", in: Brent G. Wilson, ed. (1996): *Constructivist Learning Environments: Case Studies in Instructional Design*: Educational Technology Publications: 165–175.

Dede, Chris (2009): "Immersive Interfaces for Engagement and Learning", Vol. 323, *Science*: 66–69.

Dekker, Gerald A., Moreland, John, and van der Veen, Jatila (2011): Developing the Planck Mission Simulation as a Multi-Platform Immersive Application, *3rd World Conference on Innovative Virtual Reality (WINVR)*, June 27–29, Milan, Italy.

Engeström, Yrjö (1999): "Activity theory and individual and social transformation", in: Yrjö Engeström, Reijo Miettinen and Raija-Leena Punamäki, eds. (1999): *Perspectives on Activity Theory*, Cambridge, UK: Cambridge University Press: 19–38.

Entwistle, Noel (2005): "Learning outcomes and ways of thinking across contrasting disciplines and settings in higher education", Vol. 16, *Curriculum Journal*: 67–82.

Falconer, Liz, and Frutos-Perez, Manuel (2009): Online Simulation of Real Life Experiences; the Educational Potential, *21st World Conference on Educational Multimedia, Hypermedia & Telecommunications (Ed-Media)*, June 22–26, Honolulu, Hawaii.

Fominykh, Mikhail, and Prasolova-Førland, Ekaterina (2011): Virtual Research Arena: Presenting Research in 3D Virtual Environments, *2nd Global Conference on Learning and Technology (Global Learn Asia Pacific)*, March 28–April 1, Melbourne, Australia.

Fominykh, Mikhail, and Prasolova-Førland, Ekaterina (2012): "Educational visualizations in 3D collaborative virtual environments: a methodology", Vol. 9, *Interactive Technology and Smart Education*: 33–45.

Fominykh, Mikhail, Prasolova-Førland, Ekaterina, and Divitini, Monica (2012): Learning Computer-Mediated Cooperation in 3D Visualization Projects, *9th International Conference on Cooperative Design, Visualization and Engineering (CDVE)*, September 2–5, Osaka, Japan.

Fominykh, Mikhail, Prasolova-Førland, Ekaterina, Hokstad, Leif Martin, and Morozov, Mikhail (2014): Repositories of Community Memory as Visualized Activities in 3D Virtual Worlds, *47th Hawaii International Conference on System Sciences (HICSS)*, Waikoloa, HI, USA.

Foronda, Cynthia, Godsall, Lyndon, and Trybulski, JoAnn (2013): "Virtual Clinical Simulation: The State of the Science", Vol. 9, *Clinical Simulation in Nursing*: e279-e286.

Goel, Lakshmi, Johnson, Norman, Junglas, Iris, and Ives, Blake (2013): "Predicting users' return to virtual worlds: a social perspective", Vol. 23, *Info. Sys. Jour.*: 35–63.

Greenhalgh, Chris, Flintham, Martin, Purbrick, Jim, and Benford, Steve (2002): Applications of Temporal Links: Recording and Replaying Virtual Environments, *Virtual Reality (VR)*, March 24–28, Orlando, FL, USA.

Gu, Ning, Williams, Anthony, and Gül, Leman Figen (2007): Designing & Learning in 3D Virtual Worlds, *4th International Conference on Cognition and Exploratory Learning in Digital Age (CELDA)*, December 7–9, Algarve, Portugal.

Hansen, Margaret M. (2008): "Versatile, immersive, creative and dynamic virtual 3-D healthcare learning environments: A review of the literature", Vol. 10, *Journal of Medical Internet Research*.

Harrison, Steve, and Dourish, Paul (1996): Re-place-ing space: the roles of place and space in collaborative systems, *ACM conference on Computer supported cooperative work*, Boston, MA.

Hayes, Elisabeth R. (2006): Situated Learning in Virtual Worlds: The Learning Ecology of Second Life, *American Educational Research Association Conference*.

Hendaoui, Adel, Limayem, Moez, and Thompson, Craig W. (2008): "3D Social Virtual Worlds: Research Issues and Challenges", Vol. 12, *IEEE Internet Computing*: 88–92.

Hill, Valerie, and Lee, Hyuk-Jin (2009): "Libraries and immersive learning environments unite in Second Life", Vol. 27, *Library Hi Tech*: 338–356.

Holliman, Nicolas S., Dodgson, Neil A., Favalora, Gregg E., and Pockett, Lachlan (2011): "Three-Dimensional Displays: A Review and Applications Analysis", Vol. 57, *IEEE Transactions on Broadcasting*: 362–371.

Holloway, David (2012): "Virtual worlds and health: healthcare delivery and simulation opportunities", in: N. Zagalo, L. Morgado and A. Boa-Ventura, eds. (2012): *Virtual worlds and metaverse platforms : new communication and identity paradigms*, USA: IGI Global: 251–270.

Huang, Hsiu-Mei, Rauch, Ulrich, and Liaw, Shu-Sheng (2010): "Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach", Vol. 55, *Computers & Education*: 1171–1182.

Huxor, Avon (2001): "The Role of the Personal in Social Workspaces: Reflections on Working in AlphaWorld", in: ElizabethF Churchill, DavidN Snowdon and AlanJ Munro, eds. (2001): *Collaborative Virtual Environments*: Springer London: 282–296.

Hwang, Jihyun, Park, Hyungsung, Cha, Jiseon, and Shin, Bokjin (2008): Effects of Object Building Activities in Second Life on Players' Spatial Reasoning, *2nd International Conference on Digital Game and Intelligent Toy Enhanced Learning*, November 17–19, Banff, Canada.

Imai, Tomoko, Qiu, Zhongwei, Behara, Sowmitri, Tachi, Susumu, Aoyama, Tomonori, Johnson, Andrew, and Leigh, Jason (2000): Overcoming Time-Zone Differences and Time Management Problems with Tele-Immersion, *10th Annual Internet Society Conference (INET)*, July 18–21, Yokohama, Japan.

Jarmon, Leslie, Traphagan, Tomoko, and Mayrath, Michael (2008): "Understanding project-based learning in Second Life with a pedagogy, training, and assessment trio", Vol. 45, *Educational Media International*: 157–176.

Johnson, W. Lewis (2009): A Simulation-Based Approach to training Operational Cultural Competence, *International Congress on Modelling and Simulation (MODSIM)*.

Korakakis, George, Boudouvis, Andreas, Palyvos, John, and Pavlatou, Evagelia A. (2012): "The impact of 3D visualization types in instructional multimedia applications for teaching science", Vol. 31, *Procedia - Social and Behavioral Sciences*: 145–149.

Lee, Mark J. W. (2009): "How Can 3d Virtual Worlds Be Used To Support Collaborative Learning? An Analysis Of Cases From The Literature", Vol. 5, *Society*: 149–158.

Leigh, Jason, Ali, Mohammed Dastagir, Bailey, Stuart, Banerjee, Andy, Banerjee, Pat, Curry, Kevin, Curtis, Jim, Dech, Fred, Dodds, Brian, Foster, Ian, Fraser, Sarah, Ganeshan, Kartik, Glen, Dennis, Grossman, Robert, Heil, Y, Hicks, John, Hudson, Alan D., Imai, Tomoko, Khan, Mohammed Ali, Kapoor, Abhinav, Kenyon, Robert V., Park, Kyoung, Parod, Bill, Rajlich, Paul J., Rasmussen, Mary, Rawlings, Maggie, Robertson, Danielh., Thongrong, Samroeng, Stein, Robert J., Tuecke, Steve, Wallach, Harlan, Wong, Hong Yee, and Wheless, Glenh. (1999): A Review of Tele-Immersive Applications in the CAVE Research Network, *International conference on Virtual Reality (VR)*, March 13–17, Houston, TX , USA.

Lele, Ajey (2013): "Virtual reality and its military utility", Vol. 4, *Journal of Ambient Intelligence and Humanized Computing*: 17–26.

Leont'ev, Alexei Nikolaevich (1981): *Problems of the development of the mind*. 4 ed. Moscow: Progress.

Li, Fei, and Maher, Mary Lou (2000): Representing Virtual Places - A Design Model for Metaphorical Design, *22nd Annual Conference of the Association for Computer-Aided Design in Architecture (ACADIA)*, October 19–22.

Linde, Charlotte (2001): "Narrative and social tacit knowledge", Vol. 5, *Journal of Knowledge Management*: 160–171.

Matsuura, Kenji, Ogata, Hiroaki, and Yano, Yoneo (1999): Agent-based Asynchronous Virtual Classroom, *7th International Conference on Computers in Education (ICCE)*, Japan.

Mckerlich, Ross, Riis, Marianne, Anderson, Terry, and Eastman, Brad (2011): "Student Perceptions of Teaching Presence, Social Presence, and Cognitive Presence in a Virtual World", Vol. 7, *Journal of Online Learning and Teaching*: 324–336.

McSharry, Gabrielle, and Jones, Sam (2000): "Role-Play in Science Teaching and Learning", Vol. 82, *School Science Review*: 73–82.

Messinger, Paul R, Stroulia, Eleni, and Lyons, Kelly (2008): "A Typology of Virtual Worlds: Historical Overview and Future Directions", Vol. 1, *Journal of Virtual Worlds Research*: 1–18.

Meyer, Jan H. F., and Land, Ray (2003): "Threshold concepts and troublesome knowledge: linkages to ways of thinking and practicing", in: C. Rust, ed. (2003): *Improving Student Learning - Theory and Practice Ten Years On*, Oxford, UK: Oxford Centre for Staff and Learning Development (OCSLD): 412–424.

Minocha, Shailey, and Reeves, Ahmad John (2010): "Design of learning spaces in 3D virtual worlds: an empirical investigation of Second Life", Vol. 35, *Learning, Media and Technology*: 111–137.

Molka-Danielsen, Judith (2009): "The new learning and teaching environment", in: Judith Molka-Danielsen and Mats Deutschmann, eds. (2009): *Learning and Teaching in the Virtual World of Second Life*, Trondheim, Norway: Tapir Academic Press: 13–25.

Molka-Danielsen, Judith, Deutschmann, Mats, and Panichi, Lusia (2009): "Designing Transient Learning Spaces in Second Life - a case study based on the Kamimo experience", Vol. 2, *Designs for Learning*: 22–33.

Morozov, Mikhail, Gerasimov, Alexey, Fominykh, Mikhail, and Smorkalov, Andrey (2013): "Asynchronous Immersive Classes in a 3D Virtual World: Extended Description of vAcademia", in: MarinaL Gavrilova, C. J. Kenneth Tan and Arjan Kuijper, eds. (2013): *Transactions on Computational Science XVIII*: Springer Berlin Heidelberg: 81–100.

Neustaedter, Carman, and Fedorovskaya, Elena (2009): Capturing and sharing memories in a virtual world, *SIGCHI Conference on Human Factors in Computing Systems*, Boston, MA, USA.

Nonaka, Ikujiro, and Takeuchi, Hirotaka (1995): *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. New York: Oxford University Press.

Owen, Martin L., Grant, Lyndsay, Sayers, Steve, and Facer, Keri (2006): *Social software and learning*, Futurelab, London, UK.

Papert, Seymour, and Harel, Idit (1991): "Situating Constructionism", in: Seymour Papert and Idit Harel, eds. (1991): *Constructionism*, Westport, CT, USA: Ablex Publishing Corporation: 193–206.

Perera, Indika , Allison, Colin, Nicoll, J. Ross, Sturgeon, T., and Miller, Alan (2010): "Managed Learning in 3D Multi User Virtual Environments", Vol. 1, *International Journal of Digital Society*: 256–264.

Polanyi, Michael (1966): *The Tacit Dimension*. Glouchester, MA: Peter Smith.

Prasolova-Førland, Ekaterina (2004): A repository of virtual places as community memory: an experience of use, *SIGGRAPH International Conference on Virtual Reality Continuum and its Applications in Industry*, Singapore.

Prasolova-Førland, Ekaterina (2005): Place Metaphors in Educational CVEs: An Extended Characterization, *4th Conference on Web-based Education (WBE)*, Switzerland.

Prasolova-Førland, Ekaterina, Fominykh, Mikhail, Darisiro, Ramin, and Mørch, Anders I. (2013): Training Cultural Awareness in Military Operations in a Virtual Afghan Village: A Methodology for Scenario Development, *46th Hawaii International Conference on System Sciences (HICSS)*, January 7–10, Wailea, HI, USA.

Prasolova-Førland, Ekaterina, Fominykh, Mikhail, and Wyeld, Theodor G. (2010): Virtual Campus of NTNU as a place for 3D Educational Visualizations, *1st Global Conference on Learning and Technology (Global Learn Asia Pacific)*, May 17–20, Penang, Malaysia.

Salmon, Gilly, and Hawkridge, David (2009): "Editorial: Out of this world", Vol. 40, *British Journal of Educational Technology*: 401–413.

Sant, Toni (2009): "Performance in Second Life: some possibilities for learning and teaching", in: Judith Molka-Danielsen and Mats Deutschmann, eds. (2009): *Learning and Teaching in the Virtual World of Second Life*, Trondheim, Norway: Tapir Academic Press: 145–166.

Saunders, Carol, Rutkowski, Anne F., Genuchten, Michiel Van, Vogel, Doug, and Orrego, Julio Molina (2011): "Virtual space and place: theory and test", Vol. 35, *MIS Quarterly*: 1079–1098.

Savin-Baden, Maggi (2013): "Spaces in between us: a qualitative study into the impact of spatial practice when learning in Second Life", Vol. 11, *London Review of Education*: 59–75.

Schmeil, Andreas, and Eppler, Martin. J. (2009): Formalizing and Promoting Collaboration in 3D Virtual Environments – A Blueprint for the Creation of Group Interaction Patterns, *1st International Conference on Facets of Virtual Environments (FaVE)*, July 27–29, Berlin, Germany.

Smith, Rachel, Oblinger, Diana, Johnson, Laurence F., and Lomas, Cyprien P. (2007): *The Horizon Report*, The New Media Consortium, Austin, TX, USA: The New Media Consortium.

Styliani, Sylaiou, Fotis, Liarokapis, Kostas, Kotsakis, and Petros, Patias (2009): "Virtual museums, a survey and some issues for consideration", Vol. 10, *Journal of Cultural Heritage*: 520–528.

Surface, Eric A., Dierdorff, Erich C., and Watson, Aaron M. (2007): *Special Operations Language Training Software Measurement of Effectiveness Study: Tactical Iraqi Study Final Report*, Special Operations Forces Language Office, Tampa, FL, USA.

Thorpe, Stephen J. (2011): "Sense of Place and Emotional Connections Using Collaborative Storytelling in Second Life", Vol. 1, *International Journal of Information and Education Technology*: 292–297.

van Nederveen, Sander (2007): Collaborative Design in Second Life, *2nd International Conference World of Construction Project Management (WCPM)*, October 24–25, Delft, The Netherlands.

Vygotsky, Lev Semyonovich (1978): *Mind in society: the development of higher psychological processes*. Cambridge, MA, USA: Harvard University Press.

Walsh, James P., and Ungson, Gerardo Rivera (1991): "Organizational Memory", Vol. 16, *The Academy of Management Review*: 57–91.

Wenger, Etienne (1998): *Communities of Practice: Learning, Meaning, and Identity*. New York, NY, USA / Cambridge, UK: Cambridge University Press.

Wrzesien, Maja, and Raya, Mariano Alcañiz (2010): "Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the E-Junior project", Vol. 55, *Computers & Education*: 178–187.

Yates, Frances A. (1966): *The Art of Memory*. London: Routledge & Kegan Paul.

Youngblut, Christine (1998): *Educational Uses of Virtual Reality Technology*, Institute for Defense Analyses, Alexandria, VA, USA, D-2128.

Zensius, Natalie (2009): "Palomar Pomerado Health uses Second Life to explore the hospital of the future", *Healthcare Design*: 20–20,22,24, http://www.healthcaredesignmagazine.com/article/palomar-pomerado-health-uses-second-life-explore-hospital-future.

Zielke, Marjorie A. (2011): "The First Person Cultural Trainer Whitepaper", http://www.utdallas.edu/~maz031000/res/FPCT_White_Paper.pdf.