Designing a Demonstrator Virtual Learning Environment to Teach the Threshold Concept of Space Syntax: Seeing from the User's Perspective

Judith Molka-Danielsen, Mikhail Fominykh, David Swapp, Anthony Steed

Designing a Demonstrator Virtual Learning Environment to Teach the Threshold Concept of Space Syntax: Seeing from the User's Perspective

Judith Molka-Danielsen[1], Mikhail Fominykh[1,2], David Swapp[3] and Anthony Steed[3]

[1] Molde University College, Norway
{J.Molka-Danielsen, Mikhail.Fominykh}@himolde.no
[2] Volga State University of Technology, Russia
FominykhMA@volgatech.net
[3] University College London, United Kingdom
{a.steed, d.swapp}@ucl.ac.uk

Abstract. Space syntax is an important knowledge domain and focus of study for students of Architecture. It centers on the understanding of spaces, tectonics and volumes for the informed design of buildings or outdoor spaces. Space syntax is considered to be a threshold concept in Architecture, in that understanding and interpreting this knowledge domain is something that the learner needs to acquire in order to progress as a professional in this field. The concept of "line of sight" is a specific example of a concept in the space syntax domain. This research investigates a case of systems design of an immersive virtual learning environment to support teaching a concept of space syntax to students of Architecture. Such environments can engage, immerse and guide learners in ways not yet undertaken and may find application in workplace learning. This research explores the systems design requirements through a demonstrator that is tested by a small pilot group. One case scenario to teach the concept of "line of sight" was selected for the target design. Based on the expert feedback we designed a learning module demonstrated at the University College London CAVE-hybrid facility. The demonstrator was trialed in 16 timed trials. Several conclusions for workplace learning on the systems design choices are drawn.

Keywords: virtual learning environments, space syntax, threshold concepts, systems design, experiential learning, virtual worlds.

1 Introduction

Information Systems (IS) designers have often made analogies between the design of information systems and the design of buildings, saying that IS design is like building design in that, "Architecture, design, construction, furnishings, inhabitants, and location all play major roles in shaping the overall experience" [1]. It is not surprising then that "consideration of the end users first person perspective" would be an important approach to teaching of concepts in Architecture. And we as systems designers of Virtual Learning Environments (VLE) would seek to discover and include these requirements in the design of VLE learning module for students of Architecture. In this paper, we describe our approach of systems design of a VLE *demonstrator*. We report on the trials of the demonstrator and discuss the implications that such tools support reflective learning approaches [2] and can be suitable for students at different stages of their careers. This paper explores: What are the systems design requirements for VLEs to support learning of the threshold concept of "line of sight" in the knowledge domain of space syntax?

The remaining paper is presented as follows. In the next section, we clarify meaning of threshold concepts and the role of virtual technologies in practical experiential learning, and we present prior research in these domains. In Section 3, we give a description of our methodology for this project describing the systems design approach for the demonstrator. In Section 4, we describe our trials and observations. Section 5 discusses implications for VLE design. Section 6 gives concluding remarks.

2 Literature Review

2.1 Virtual Reality Technologies

In recent years, virtual reality (VR) technologies have been applied in teaching and learning. The main motivations for their use have been that VLE based on VR technologies are engaging as media [3] and that use of 3D media facilitates comprehension by means of situating learning materials in a context and exploiting the natural capabilities of humans to interact in 3D space [4]. In particular they investigated user interaction in immersive VR environments and found that the use of virtual content successfully changed the users' conceptual understanding of the content [4]. A key characteristic that motivates the use of VR in training is that participants behave in a way that is similar to their behavior in comparably similar real situations [5, 6]. These studies distinguish immersive VR from desktop VR proving that in the immersive VR the participant acts, to a great extent, as they would in the real physical world. In desktop VR, this level of immersion is limited by the form and structure of the interface. General studies of the capabilities of immersive VR systems on comprehension have shown that these systems are preferred for tasks that are exploratory and interactive [7-9]. One study identifies that for constrained tasks that features of immersive VR are contributing to performance differences [10]. However, these studies are limited in that they have not provided requirements analysis that can predict tasks for which immersive VR environments are superior over desktop approaches.

2.2 In Search for Pedagogical Approaches

Modern pedagogic approaches have emphasized the importance of real life experience, such as in the workplace, for transforming learning objectives into knowledge that can be applied in practice. At the same time, workplace experience needs to be converted into knowledge to enable deeper learning. The information relevant for a master level of performance (aka 'theory'), traditionally, is separated from the immediate experience of competent action (aka 'practice') [11]. In the past, this conversion has been supervised by skilled experts or teachers using shared experience and direct instruction. Various media, such as textbooks or instructional films, have been used as information containers. However, with recent technical advances in virtual and augmented reality, new opportunities arise for training that do not rely on strict separation of knowledge from its application.

Knowledge appears in many forms. Tangible knowledge may be stored as written instructions or in databases. Intangible knowledge appears as activity, practice, relation between participants, and in their shared experience. The former type of knowledge is known as explicit and the latter as tacit [12] [13].

Tacit knowledge can be converted to explicit knowledge through narratives – in addition to iterative training that aim to create embodied experience through activity [14]. Immersive VR as well as augmented reality provides an embodied dimension that makes users interact in the same way they do in a real context. [15, 16]

Approaches, such as experiential learning [17] and problem-based learning [18], have been applied in classrooms and have been intended for acquiring workplace skills. While having correct objectives, these approaches often fall short of supports for the transformative process necessary for the learner to capture core concepts within the targeted discipline.

2.3 Threshold Concepts

The core concepts referred to here are identified as *threshold concepts*. Erik Meyer and Ray Land state, "A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, interpreting, or viewing something without which the learner cannot progress" [19].

These necessary knowledge components represent transitions in understanding [20]. While struggling with a new way of perceiving the practices of a discipline, the learner is in a state of liminality before finally grasping the concept and passing the threshold [21].

Threshold concepts among other qualities are difficult to perceive and comprehend for the newcomers in a community of practice. Experts differ from the newcomers not only by the level of their skills, but by deeper understanding of the discipline, the profession, and, in other words, of the threshold concepts. Such understanding is often connected to tacit knowledge [17]. Access to such knowledge is therefore important and necessary for a professional to achieve the level of expert in a discipline. Land and Meyer state further that threshold concepts are central "core" concepts within a discipline that are essential in the acquisition of creative thinking, learning and communication of understanding within a discipline [19, 22-24].

There is a documented lack of support for threshold experiences in higher education [25]. However, we have recently explored teaching threshold concepts with the support of VR technologies [26] and identified conceptual requirements for systems design [27]. This study extends the research of [27] in that it designs and pilot tests a demonstrator of a VLE that aims to support an exploratory and interactive learning task for Architecture students. The demonstrator is designed with use of immersive VR technologies that are described in the next section.

3 Methodology

This research applies the general steps of Design Science Research (DSR) as an approach to design the demonstrator artifact that is a learning module implemented in a VLE. We selected DSR as recent studies for developing user innovation in virtual world's shows that DSR can be used as problem solving process to develop IS artifacts [28-30]. Through a cyclical process of design of the learning module, a better understanding of the users experience and design requirements are obtained. The general steps of DSR are: problem awareness, suggestion, development, evaluation and conclusion. At each stage of development, evaluation and conclusion, knowledge is gained and fed back into problem awareness, thus influencing suggestions for further improvements. The DSR approach was useful in that it allowed us the designers of the VLE, to study how a trial group learned. We conducted the following steps:

1. *Problem Awareness*: Through interviews with experts in the selected field of learning, Architecture, we recognize difficulties with traditional learning methods.
2. *Suggestion*: The knowledge gained from the interviews and designers knowledge of VLE technologies influence the initial development of the learning module.
3. *Development*: The learning modules are implemented using two software implementations to allow control for the influence of the software interfaces on the trials.
4. *Evaluation*: The demonstrators are evaluated by general users in timed trials.
5. *Conclusion*: The designers draw conclusions based on the observation of the trials.
6. *Cycle-2*: Further cycles are suggested with use of several trial groups of Architecture students at different points in their progression of study.

3.1 Problem Awareness and Suggestion

In September 2013, the researchers conducted interviews with Architecture experts Dr. Sean Hanna (SH, Space and Adaptive Architectures, UCL) and Dr. Sam Griffiths (SG, Urban Morphology and Theory, UCL). The information from these interviews was used to inform the learning module that would be implemented in the VLE. Some of the statements of the interviews are summarized as follows:

- SH: “Space syntax” is a long threshold concept. This is a very broad theme, and the knowledge domain for a master’s level program. SH says that students that have mastered the concepts of space syntax make different assessments and decisions as applied to architectural designs. This has been tested in students’ responses to school assignments and even in master’s thesis.
- SH: Issues such as “lines of sight”, “where people are likely to move, gather around objects, meet others”, are related to understanding of space syntax.
- SH: The way that students think about “spaces, tectonics, and volumes” is part of a long threshold in Architecture. Students that know about design space syntax are more likely to use those concepts in design decisions.
- SG: Points out that there are some students who you can see that “get it” and that these are distinguishable from those who may struggle with the tools and models. While understanding the tools and models, these can give very delineated responses to questions. However, the questions are sometimes complex and do not have simple responses.
- SG: Most of the tools and visual presentations of their work are done in 2D. The work presented in 2D only is a challenge for students with little work experience to transform that view in a classroom exercise into an integrated analysis of the space syntax. The use of 3D tools in itself offers another perspective that can be helpful in learning.

We concluded at this stage to develop a module that would function in a Cave Automatic Virtual Environment (CAVE), as described in the next section. The aim is that a simulation in the CAVE that provides a real-time feedback would help in the student's integrated analysis.

3.2 Development Components of the Immersive 3D VLE

The platform applied in this research made use of CAVE, an immersive projection technology [31]. A CAVE is typically a cube-shaped display that the user stands inside. The CAVE surrounds the user, thus excluding other distractions and allowing the participant to move about un-constrained by the need to face a specific desktop display. The wide field of view allows natural peripheral observation and gaze control.

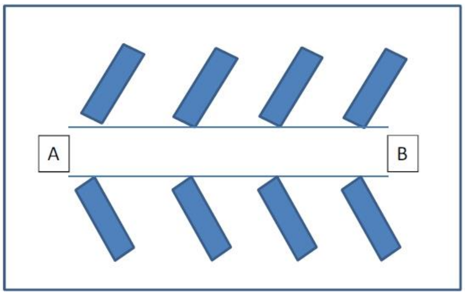
More specifically, this research was conducted as part of a visiting scholar research project (see acknowledgements) in cooperation with the Virtual Environments and Computer Group (VECG) of the CS Dept. at University College London. The project applied VECG group computers and immersive visualization facilities. The VECG group of the Department of Computer Science (UCL-CS) has excellent visualization facilities including a four-sided CAVE-hybrid driven by a PC cluster (four client nodes with GeForce Quadro 5600 graphics), a six-camera Vicon motion-tracking system, an eight camera Optitrak system, an Intersense wireless tracking system, head-mounted VR and augmented reality displays, a GRAB haptic interface and various other tracking systems and input devices including bio-signal amplifiers.

This research applied two virtual world technologies that are normally accessed through desktop interfaces. However, the learning modules were instantiated (brought up) in the CAVE. These virtual world technologies were vAcademia™ (vA), a VLE software that was created especially for educational purposes [32], and Second Life™ (SL) a general purpose virtual world software that has been widely adopted also for non-educational purposes. The implications for this study were that the researchers had access to more server side hooks for vA when bringing up simulations in the CAVE. With use of two virtual world technologies we also control for some behavior differences that can be due to perspectives afforded by the different interfaces.

3.3 Demonstrator Design

In the next phase of the project, we developed a learning module that is based on a prior design of Kalff et al. [33]. The demonstrator activity is shopping for items in a food store. In our scenario, the participant is to look for and identify three items on the shelves in a food store. Our model has eight shelves. There are two perspectives of the shelves and in the VLE models and both perspectives are replicated in SL and vA. That is we have made two separate builds for each perspective. The perspectives are with shelves pointing towards the participant ("plus" or A) and with shelves pointing away from the participant ("minus", B).

The 2D overhead view of the VLE scene is depicted below (Fig. 1, left). A person would stand at point A or B. In general, the perspective of B should result in faster times for participants to locate and identify items in the food store. This would be a typical "line of sight" exercise for a new student in Architecture.



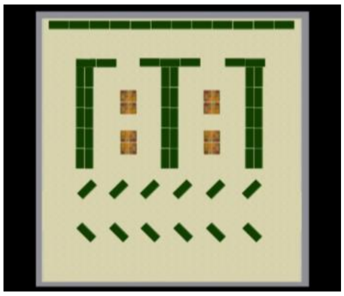


Fig. 1. The Learning Scenario in a VLE (left) and a 2D layout of a food store (right)

For a participant to look at the 2D representation above, it can be difficult to visualize which perspective is more effective. With the help of a 3D representation, the "better" design could be more easily identified. Applying the 3D representation would be seeing from the end user's perspective, that is, the shopper's perspective. A more experienced Architecture student might be given more delineated tasks. For example, they might be asked to determine the best angle of the shelves. This was not asked in these trials.

4 Trials and Observations

We conducted trials of the learning module with five volunteer participants, using a Think-aloud protocol [34] to gather data. Participants were asked to talk about what they were doing while active in the trials. The trials were video recorded to not interfere with the participants while they completed their tasks. All had prior experience with virtual reality environments. They gave verbal consent for use of video recording of their trials. We first showed them a 2D diagram of a food store (Fig. 1, right) and asked which perspective would be their preferred starting point (A or B). Although everyone did choose B, most of the responders were hesitant and unsure. We then had the participants try out the module in SL (Fig. 2) and in vA (Fig. 3).

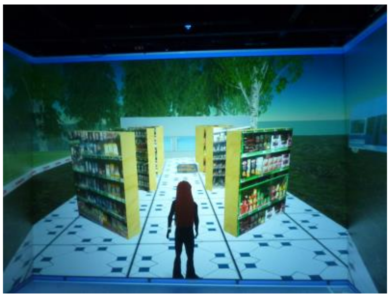



Fig. 2. Trials in SL: Plus perspective – A point (left) and Minus perspective – B point (right)


Fig. 3. Trials in vA: Plus perspective – A point (left) and Minus perspective – B point (right)

All five participants trialed the module in vA and three of them in SL (Table 1). We used the ‘identification times’ as an objective metric of their effort for location of three items in the food store. In all trials, the ‘identification‘ time values were smaller for perspective B, even when the items sought after were made different across trials. This trend was consistent across both VLE platforms.

As an affective measure of participants' feelings of the learning experience we asked after the trials if they had any comments about the two perspectives. All responded that it was immediately obvious that B was "easier" or "better" that "I can see everything in B, but in the other (A) my view is blocked". Some noted that it was also a more pleasant shopping experience with B, as it was so hard to move around in the VLE and with B they did not have to move the avatar so much. Many commented that in real life grocery stores, that store owners want you to walk around, and maybe wanted customers to not find items so quickly. Some participants of the exercise noted that items were easier to see/identify in vA than in SL. We attribute this to the fact that first person perspective functioned in the vA trials, giving a better view. And, only third person perspective functioned in SL in the CAVE. However, some commented that it was easier to move around in SL. In both VLEs, the participants controlled the movement of the avatar using a keyboard. The model in vA had shelves inside a four-walled store; while alternatively, the model in SL had shelves on an open plane. So the reason for some longer identification times in vA may have been the presence of the walls, as sometimes the users' camera view was obstructed when standing too close to the walls. While the number of trials is too few to make performance comparisons of the two VLEs, future designs could be created in open spaces to avoid confusions caused by misaligned camera views.

Table 1. Trial Times according to VLE and Perspective

VLE	Perspective	Items to Find	User (U); Trial (T)=Time to locate the item
SL	**A**	• Orange Juice, Tooth paste, Milk • Pasta, Tooth paste, Olives • Tomatoes, Tomato sauce, Yoghurt	U3;T365=1min 42sec U4;T384=0min 50sec U5;T387=1min 15sec
SL	**B**	• Yoghurt, Pasta, Olives • Milk, Cabbage, Lunch Meat • Milk, Cabbage, Pasta	U3;T366=0min 30sec U4;T383=0min 35sec U5;T388=0min 33sec
vA	**A**	• Orange Juice, Tooth paste, Crisps	U1;T351=1min 50sec U2;T354=2min 30sec U3;T369=1min 20sec U4;T374=2min 15sec U5;T378=1min 00sec
vA	**B**	• Yoghurt, Pasta, Olives	U1;T353=0min 30sec U2;T357=0min 50sec U3;T373=0min 26sec U4;T375=0min 42sec U5;T379=0min 35sec

5 Implications for VLE Systems Design

This study gives evidence that VLEs hold potential to support of learning of threshold concepts through experiential learning approach. A demonstrator of one threshold learning scenario was implemented and trialed in the CAVE using two VLE platforms. The primary implications of this research are summarized in Table 2.

Table 2. Implications for VLE systems design

Implications
• Learning with your virtual body – the VLE supported the learning of threshold concepts through the interaction of the learner (through their avatar) with the 3D virtual environment. In brief, walking around in the store in the demonstrator had the feel of walking around a store in real life.
• First person view perspective – was one of the features that was most important in the ability to read items on the shelves and to move naturally around. This was not apparent to an outside observer that views 2D video recordings of movement in the virtual environments. But, it was reported as important by those participating in the trials.
• The students were informed by their experience in the trials that enabled them to "see from the user's perspective" – however, that perspective will depend on who is the user. The trial participants realized during the trials that a customer in a food store will want to find items quickly, while a shop manager will want the customer to spend more time in the shop.
• Learning takes place after becoming familiar with the technical interface and moving around in the VLE – when the users became more familiar with the VLE interface controls, they were able to focus on the cognitive task. The comments then focused more on which architectural perspective was better, rather than on the VLE interface. A pre-task interaction session is recommended for all learning modules.

We conclude that several VLE design factors were important and can contribute to better workplace learning environments that support experiential reflective learning. These are:

1. First person view is important for achieving realistic lines of vision/sight (Fig. 3). The use of third person view in SL places the user above the scene (Fig. 2). In addition, as one user pointed out, it is harder to get closer (next to) the shelves in third person view, and so it is more difficult to see and identify the items.
2. Choices of interface tools are important. Several commented a joystick would have enabled easier movement as opposed to the application of keyboard for movement. The choice of "easier movement" would represent more accurately the real life ease of walking around in a food store.
3. The food items on the shelves in the store models were placed with no specific logic next to each other. For example, refrigerated items (e.g., orange juice) could be on shelf next to dry storage items (e.g., toothpaste). In addition, the color of the shelves were green, indicating dry storage space, and this did not make sense to one participant that was looking for orange juice in a cold refrigeration unit that should be white. Obliviously, the placement of items in the model is not how the items would be located in stores in real life. In brief, during trials the participants could not rely on internalized experience models of normal layouts of food stores.

While done purposely for this exercise, course designers and VLE designers might consider multiple layouts when testing learning outcomes.

4. The model of the scene and avatar in the 3D (e.g. CAVE environment) should be built to a 1:1 scale as they would be in real life. That is if the participant is using first person view, the size of the objects should be on a 1:1 scale with the size of the avatar. For example, the shelf height should be designed as in real life, on average about 2–2.5 meters for a 1.6–2 meter tall person. The reason for doing this is, if a shelf height of a three meters is used, the top of the shelf could not be viewed in first person view mode, unless the avatar would take a step away from the object. This was at least what our participants experienced in the CAVE. Alternatively, the issue of scale is not as important for a PC desktop interface. That is because when using a PC desktop interface the user often uses a third person view to find items. As such, the scales of objects (items and shelves) are often made larger in respect to the avatar than they would be in real life, to take advantage that the objects in the desktop module would fill more screen space.

Regarding the four points above, it is clear that VLE design choices had implications for how the participant saw the environment and solved problems.

6 Concluding Remarks

In summary, this paper explored the systems design requirements for the design of VLE for teaching an architectural threshold concept of "line of sight" within the knowledge domain of space syntax. Our research used a DSR approach to design a demonstrator that contributes to a proof-of-concept, that VLE can be applied to support learning of a threshold concept. This was demonstrated in two different VLEs. We described the implementation and analysis of a demonstrator of a threshold learning scenario in the CAVE and assessed the system elements that would support that environment. We identified some basic factors about the software and hardware components that need to be considered in VLE design to be more supportive of a workplace learning environment. Last, we created a testing environment that can be replicated, modified and applied in future research projects.

For further DSR cycles of the VLE design, we recommend testing of the modules with Architect students at various stages of their career including those with workplace experience. Educators could also change tasks and apply different assessment methods. Future changes to this design should explore the question: can the VLE be a learning aid for those who already "get it". That is, more experienced professionals may already comprehend the threshold concept, but may struggle with it in different contexts.

Finally, we think the DSR approach may be applied to the design of other VLE scenarios for workplace training and for teaching threshold concepts in other knowledge domains. For example, possible scenarios could include re-training for new equipment or settings in industry, continuous training in medicine, and threat detection in emergency management. In such a case, VLEs can be used as tools for vocational training. Creating more learning scenarios and trialing these with expanded target groups is a natural next step.

Acknowledgements

The research leading to these results has received funding from the European Commission's Research Infrastructure Action – grant agreement VISIONAIR 262044 - under FP7/2007-2013. The author wishes to thank Mikhail Morozov, Maksim Tsukanov and Andrey Smorkalov from the support team of vAcademia at Volga State University of Technology, RU, for their contribution of the development of the VLEs.

References

1. Morville P., Rosenfeld L.: Information Architecture for the World Wide Web. O'Reilly Media, Sebastopol, CA (2007)
2. Boud, D., Keogh, R., & Walker, D. (Eds.). (1985). Reflection: Turning Experience into Learning. London: Kogan Page.
3. Winn W., Windschitl M., Fruland R., Lee Y.: When does immersion in a virtual environment help students construct understanding. In: Fifth International Conference of the Learning Sciences, Seattle, Washington, 23–26 October 2002, pp. 497–503. ICLS, Chicago IL, USA (2002)
4. Roussou M., Oliver M., Slater M.: The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. Virtual Reality 10 (3-4), 227–240 (2006)
5. Sanchez-Vives M.V., Slater M.: From presence to consciousness through virtual reality. Nat Rev Neurosci 6 (4), 332–339 (2005)
6. Slater M.: Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments. Philosophical Transactions of the Royal Society of London 364 (1535), 3549–3557 (2009)
7. Demiralp C., Jackson C.D., Karelitz D.B., Song Z., Laidlaw D.H.: CAVE and fishtank virtual-reality displays: a qualitative and quantitative comparison. Visualization and Computer Graphics, IEEE Transactions on 12 (3), 323–330 (2006)
8. Prabhat F.A., Katzourin M., Wharton K., Slater M.: A Comparative Study of Desktop, Fishtank, and Cave Systems for the Exploration of Volume Rendered Confocal Data Sets. Visualization and Computer Graphics, IEEE Transactions on 14 (3), 551–563 (2008)
9. Swindells C., Po B.A., Hajshirmohammadi I., Corrie B., Dill J.C., Fisher B.D., Booth K.S.: Comparing CAVE, wall, and desktop displays for navigation and wayfinding in complex 3D models. In: Computer Graphics International, Crete, Greece, 16–19 June 2004, pp. 420–427. IEEE, New York, USA (2004)
10. Ragan E.D., Kopper R., Schuchardt P., Bowman D.A.: Studying the Effects of Stereo, Head Tracking, and Field of Regard on a Small-Scale Spatial Judgment Task. IEEE Transactions on Visualization and Computer Graphics 19 (5), 886–896 (2013)
11. Fominykh M., Wild F., Smith C., Alvarez V., Morozov M.: An Overview of Capturing Live Experience with Virtual and Augmented Reality. In: 1st Immersive Learning Research Network Conference (iLRN), Prague, Czech Republic, July 13–14. IOS Press, Amsterdam, Netherlands (2015)

12. Polanyi M.: The Tacit Dimension. Peter Smith, Glouchester, MA (1966)
13. Lam A.: Tacit Knowledge, Organizational Learning and Societal Institutions: An Integrated Framework. Organization Studies 21 (3), 487–513 (2000)
14. Jang, S., Black, J. B. and Jyung, R. W. (2010). Embodied Cognition and Virtual Reality in Learning to Visualize Anatomy. 32nd Annual Conference of the Cognitive Science Society, Portland, OR, Cognitive Science Society, 2326–2331.
15. Mennecke, B.E., Triplett, J. L., Hassall, L. M, Conde, Z. J. & Heer, R. (2011). An Examination of a Theory of Embodied Social Presence in Virtual Worlds. Decision Sciences, (42) 413-450.
16. Mennecke, B.E., Triplett, J. L., Hassall, L. M, & Conde, Z. J. (2010). Embodied Social Presence Theory. Paper presented at the 43rd HICSS, Hawaii, US.
17. Kolb, D.A. (1984) *Experiential Learning*, Engelwood Cliffs.
18. Gijselaers, W.H. (1996) 'Connecting problem based practices with educational theory', in L. Wilkerson and W.H. Gijselaers (Eds.) *Bringing Problem-Based Learning to Higher Education: Theory and Practice*, San Francisco: Jossey-Bass, pp.13–21.
19. Meyer J.H.F., Land R.: Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practicing within the Disciplines. ETL Project Occasional Report, No. 4., (2003), http://www.etl.tla.ed.ac.uk/docs/ETLreport4.pdf
20. Meyer J.H.F., Land R.: Threshold concepts and troublesome knowledge: linkages to ways of thinking and practicing. In: Rust C (ed.) Improving Student Learning - Theory and Practice Ten Years On. pp. 412–424. Oxford Centre for Staff and Learning Development (OCSLD), Oxford, UK (2003)
21. Meyer J.H.F., Land R.: Threshold concepts and troublesome knowledge: issues of liminality. In: Meyer JHF, Land R (eds.) Overcoming barriers to student understanding: threshold concepts and troublesome knowledge. pp. 19–32. Routledge, Abingdon, UK (2006)
22. Meyer J.F., Land R.: Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning. High Educ 49 (3), 373–388 (2005)
23. Meyer J.H.F., Land R., Davies P.: Threshold concepts and troublesome knowledge (4): Issues of variation and variability. In: Land R, Meyer JHF, Smith J (eds.) Threshold concepts within the disciplines. Educational futures rethinking theory and practice, pp. 59–74. Sense Publishers, Rotterdam ; Taipei (2008)
24. Perkins D.: The constructivist classroom - the many faces of constructivism. Educational Leadership 57 (3), 6–11 (1999)
25. Perkins D.: Threshold Experience. 3rd Biennial Threshold Concepts Symposium, Keynote Address. Sydney (2010)
26. Fominykh M., Prasolova-Førland E., Hokstad L.M., Morozov M.: Repositories of Community Memory as Visualized Activities in 3D Virtual Worlds. In: Ralph H. Sprague J (ed.) 47th Hawaii International Conference on System Sciences (HICSS), Waikoloa, HI, USA, pp. 678–687. IEEE, New York (2014)
27. Molka-Danielsen J., Savin-Baden M., Steed A., Fominykh M., Oyekoya O., Hokstad L.M., Prasolova-Førland E.: Teaching Threshold Concepts in Virtual Reality: Exploring the Conceptual Requirements for Systems Design. In: Fallmyr T (ed.) Norsk konferanse for organisasjoners bruk av informasjonsteknologi (NOKOBIT), Stavanger, Norway, November 18–20, pp. 93–106. Akademika forlag, Trondheim, Norway (2013)
28. Vaishnavi V., Kuechler W.: Design research in information systems. DESRIST.org (2004), http://desrist.org/design-research-in-information-systems/
29. Spence J.: The Researcher's Toolbox. Journal of Virtual Worlds Research 3 (1), (2010)

30. Hevner A.R., March S.T., Park J., Ram S.: Design Science in Information Systems Research. Management Information Systems Quarterly 28 (1), 75–105 (2004)
31. Cruz-Neira C., Sandin D.J., DeFanti T.A., Kenyon R.V., Hart J.C.: The CAVE: audio visual experience automatic virtual environment. Communications of the ACM 35 (6), 64–72 (1992)
32. Morozov M., Gerasimov A., Fominykh M.: vAcademia – Educational Virtual World with 3D Recording. In: Kuijper A, Sourin A (eds.) 12th International Conference on Cyberworlds (CW), Darmstadt, Germany, September 25–27, pp. 199–206. IEEE, New York (2012)
33. Kalff C., Kühner D., Senk M., Conroy Dalton R., Hoelscher C.: Turning the Shelves: Empirical findings and Space Syntax analyses of two virtual supermarket variations. In: Hölscher C, Shipley TF, Belardinelli MO, Bateman JA, Newcombe NS (eds.) Spatial Cognition, Mt. Hood, Oregon, USA, 15–19 August 2010, LNAI, pp. 25–48. Springer, Berlin Heidelberg (2010)
34. Lewis C., Rieman J.: Task-Centered User Interface Design: A Practical Introduction. Department of Computer Science, University of Colorado Boulder, USA (1993), http://dcti.iscte.pt/cgm/web/TCUID_PI.pdf