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Teaching Threshold Concepts in Virtual Reality: Exploring the Conceptual Requirements for Systems Design

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ABSTRACT

In a complex world students need to be equipping with a range of capabilities that will enable them to be critical and flexible learners and citizens. The central research objective in this paper is to explore the argument that virtual reality (VR) technologies, collaborative learning approaches and recognition of the values and importance of thresholds to learning are components that can equip students in and for the future. Threshold concepts are specific concepts which are identified as essential in the acquisition of thinking, learning and communication of understanding within a specific subject of learning. Threshold experiences occur when learners identify moments of "learning leaps" which are cognitive transformations or changes in conceptual role for the learner, enabling them to work at higher levels of abstraction and creativity. Virtual reality technology is increasingly applied in education and can be used to test multiple threshold concepts and applied to open problems that allow for low-stress and real-time interactions as well as supporting collaborative groups with rapid interactions. Applications built on VR can engage, immerse, and guide learners in ways not yet undertaken in the education of threshold concepts. Through literature review we explore the definitions of threshold concepts, VR technologies, and the opportunities for teaching threshold concepts using VR technologies. We additionally predict possible limitations of the technologies. Further, we propose a systems design approach as informed by our literature review.

KEYWORDS

Threshold concepts, virtual world technology, virtual learning environments, learning

1. INTRODUCTION

Several critics have pointed to the new and emerging challenges to the educational system and in - service training. Barnett has described the modern world as super complex (Barnett 2000). In his perspective the role of the university is to prepare the students for a world in constant change, being exposed to several and sometimes conflicting frameworks for understanding. The challenge for higher education is to prepare for unpredictability and uncertainty. Houston identified several needs of present day learners to include: a growing demand for broad competencies prioritizing creative problem solving skills and complex communication skills. Modern challenges in medicine, engineering, architecture and urban planning are highly complex, and solutions may be found only by crossing discipline borders and by defining new and emergent ontologies (Houston 2007). It is often acknowledged that these emergent skills may not be imparted by traditional formal learning methods of classroom instruction with passive recipients, but rather through greater application of active learning approaches. Traditional competence based training also fail to adequately address such complex issues (Kinchin et al., 2007; Stacey and Stickley 2012).

Virtual reality (VR) technologies present opportunities to support the present day needs of learners. Research and applications of VR technologies in teaching and learning are at present motivated by the technology's support for collaboration and immersive experiences where effectiveness of learning is the objective. These technologies supporting 3D visualization and interaction may potentially enhance the understanding of complex subjects by learning through observation and interaction, replay and reflection.

Pedagogic approaches in practitioner domains emphasize the importance of real life experience for transforming learning objectives into knowledge that can be applied in practice. Such learning approaches (e.g., Experiential Learning Theory, PBL) while they have correct objectives, often fall short of supports for the transformative process necessary for the learner to capture core concepts within the targeted discipline. Such concepts are called threshold concepts. Threshold concepts are essential core concepts within a discipline that are essential in the acquisition of creative thinking, learning and communication of understanding within a discipline (Meyer & Land, 2003). There is a documented lack of support for threshold experiences in higher education (Perkins, 2010). The needs of present day learners motivate us to explore the opportunities of virtual reality technologies for the teaching of threshold concepts.

The central argument of this paper is that in this super complex world (Barnett, 2000) students need to be equipping with a range of capabilities that will enable them to be critical and flexible learners and citizens. The challenge for higher education is to prepare for unpredictability and uncertainty yet much current pedagogy do not prepare students for such a world. This paper argues that virtual reality (VR) technologies, collaborative learning approaches and recognition of the values and importance of thresholds to learning are components that can equip students in and for the future.

This paper provides a literature review of threshold concepts in learning and reviews former research in the application of VR technologies in learning, provides a design approach and suggests areas for development in the future discuss the steps ahead for system development in this area. The final section offers our concluding remarks.

2. LITERATURE REVIEW

In this section we present a literature review that introduces the role of threshold concepts in creativity and learning. We follow this by a review of the role of virtual world technologies in education.

Our selection of literature is based on the principle stated by Hart (1998). He states, "The selection of available documents (both published and unpublished) on the topic, which contain information, ideas, data and evidence. This selection is written from a particular standpoint to fulfill certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed." (Hart, 1998, p. 13) Finally, we prescribe that our literature review should aid in selection of the methodology for further systems development.

2.1 The Conceptual Role of Threshold Concepts in Creativity

Erik Meyer and Ray Land (2003, p. 1) 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”. Further, in their framework, threshold concepts are characterized by the following features (Cousins, 2006, p. 4):

- Transformative – because it involves an ontological as well as a conceptual shift
- Irreversible – once understood the learner is unlikely to forget it
- Integrative – in that it exposes the hidden interrelatedness of phenomenon
- Bounded – in that ‘any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas’ (Meyer and Land, 2006, p. 6)
- ‘Troublesome knowledge’, are involved; ‘that which appears counter-intuitive, alien (emanating from another culture or discourse), or seemingly incoherent’ (Perkins in Meyer and Land, 2003, p. 7).
- Discursive – the crossing of a threshold will result in a deeper understanding of the language of a discipline (Meyer and Land, 2005)
- Liminality – refers to the state of mind of the learner as he encounters the troublesome aspect in his learning trajectory. Akin to a ′rite of passage′ the learner experiences a “messy journey back and forth and across the conceptual terrain (Cousin, 2006).

The learner seeks to acquire use of threshold concepts through an increased state of internalization of said concepts. Threshold concepts are acquired through “threshold experiences” when learners identify moments of “learning leaps” which are described as cognitive transformations where there is a conceptual change in the role of the learner, such that they are able to work at higher levels of abstraction and creativity. The “learner leaps” are characterized by increases in learner’s fluidity, creativity and speed of cognition are identifiable with a progression of roles. These roles are to think about threshold concepts as: (1) objects of study; (2) as tools (that can be applied to problems); and (3) as part of an internalized frame. In the third state, the learner is able to transcend their role to make use cognitive tools such as rapid pattern recognition, crystallization of concepts, and quick intuitive interpretation of plans. (Perkins, 2010) Perkins uses the example of using grammar in foreign language, where the student progresses from thinking about objects of grammar that can be applied; selecting among several operative concepts; to internalization of concepts within an integrative frame that can be applied as full fluency.

2.2 Theory: Threshold Concepts, Learning, and more

The overarching temporary real life identity of student carries with it many possibilities of entering liminal spaces after a period of ‘being stuck’. In the main, students are initially worried rather than excited about being stuck. For example, being usually begins as a negative experience, painful to wrestle with, and can be made worse by avoidance or retreat, although ultimately can be positive if dealt with successfully. This stuck place if often a liminal state Liminality, (from Latin, *limen* – threshold) is a betwixt and between state in which the learner finds themselves before passing though a portal into a sense of understanding. This transition through the portal can be both a barrier and a source of engagement with creativity. However, as yet threshold concepts and students engagement with liminality in the context of creativity in 3D VR technologies has not yet been explored. Further it would seem that that there are variations in liminality as defined by Meyer et al. (2008), that bear further exploration in relation to engagement and creativity.

We recommend that research is needed in Virtual Reality (VR) system design to go beyond the state of the art by analyzing the possibility of shifting away from the notion of fixed threshold concepts and exploring conceptual threshold crossing (Wisker and Savin-Baden, 2009). By building on theories of threshold concepts but not seeing them as static concepts it will be possible to recognize ‘learning leaps’, through which pedagogical shifts occur in context of creativity.

2.3 Threshold concepts and scenario building in 3D environments

VR technology has long held promise for teaching and learning. The main arguments for their use are that 3D environments are engaging as media (Winn et al., 2002), and that the use of 3D rather than 2D media facilitates comprehension by the means of situating learning materials in a context, and exploiting the natural capabilities of humans to interact in 3D space (Roussou et al., 2006).

Engagement in Learning Simulations

Studies have shown that learning in 3D environment can provide a more effective, motivated way of learning than traditional classroom practices (Youngblut, 1998; Monahan 2008; Trindade et al., 2002). Roussou et al. (2006) investigated user interaction in immersive VR environments and found that the use of virtual content successfully changed the users’ conceptual understanding of the content. The variety of content that has shown benefit from use in a VR system ranges from representations of physical systems (e.g., ‘Virtual Puget Sound' (Winn et al., 2002)) through language learning (Rose and Billinghurst, 1995) to mathematics (Maitem et al., 2012). The capabilities of emerging digital visual technologies may help in enhancing visual thinking and learning, as highlighted by Mones-Hattal et al. (1995).

Relatively few learning simulations have been built for immersive VR, though the evidence of use in very high-value training (vehicle simulation such as aircraft simulators, or military training) is compelling. There has been extensive study of the impact of 3D immersive visualization on user behavior, lower-level task performance, and comprehension of data. A key characteristic, arguably the one that motivates the use of immersive VR in high-value training, is that participants tend to react as if the scene they were seeing were real. That is they behave in a way that is similar to their behavior in a comparable real situation (Sanchez-Vives and Slater, 2005; Slater, 2009). This behavioral response itself distinguishes an immersive VR from other media even desktop VR, because when immersed the participant can actually act to a limited extent, as they would in the real world (e.g., by moving away from a threat). In desktop VR or other media, this capability is severely limited by the form and structure of the interface. There have been many studies of the relative capabilities of immersive VR and desktop VR systems on comprehension. Generally, the results indicate that for survey-like tasks a desktop VR may be preferred, but for interactive, exploratory tasks, immersive VR is preferred (Demiralp et al., 2006; Forsberg et al., 2008; Swindells, 2004). However, these and other studies have not provided a complete requirements analysis that can predict tasks for which immersive VR environments are superior. This work is continuing with larger studies showing for constrained tasks, which features of immersive VR are contributing to performance differences (Ragan et al., 2012).

Cave Automatic Virtual Environment

Cave Automatic Virtual Environment (CAVE) is an immersive projection technology and a type of immersive VR. 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.

Prototype within the Study

We propose a prototype design might use a ReaCTor CAVE system. In such systems users wearing head trackers situated on a stereo shutter glasses. The user is surrounded by four large screens: floor, front, left and right walls. In addition to the near-surround visual display, speakers (one at each corner of the cube) plus a separate sub-woofer provide spatialized sound. Interaction with the environment is achieved using a hand tracker with built-in joystick and programmable buttons. The joystick controls the position and orientation while the button tends to be used for selection and manipulation. The system allows the user to act naturally while exploring the CAVE.

3D virtual worlds (vAcademia) – improving reflective learning

The technology of 3D virtual worlds (VW) – a type of desktop VR – may improve learning in many ways. They can significantly improve the demonstrativeness/visibility of educational content, facilitate collaborative activities, provide avatar embodiment, and allow interacting in an immersive environment. We secondly propose prototype design using a desktop VR platform. The recommended platform is vAcademia – a 3D VW that is designed for collaborative learning and has a special potential for learning, case-based learning, and scenario-based role-playing. The most distinctive feature of vAcademia is 3D recording, which allows capturing everything in a given location in the virtual world in process, including positions of the objects, appearance and movement of the avatars, all media contents used text and voice communication. A user can attend and work at a recorded session, not just view it as a spectator (Fig. 1). Similar functionalities were earlier realized in few desktop VR systems (Morozov et al., 2013). However, 3D recording was never developed into a convenient tool and never adopted for specific use as in vAcademia. In addition, the platform offers convenient tools for working with resultant recordings.

Currently, 3D VWs are used for reflective learning and other purposes that require recording of synchronous activities. For example, this approach is used in Machinima – collaborative film making using screen capture in 3D VW and games (Barwell, Moore, & Walker, 2011). Even though 3D VWs allow creating full context of the real-life educational process, it is usually recorded as flat 2D video, which eliminates many advantages of the technology, such as immersion and the sense of presence. 3D recording in a VW is well suited to be explored in relation to threshold concepts. The 3D recording feature allows capturing and saving the learning activity together with the context. It allows the learners to come back into an immersive environment (possibly with more participants), experience the class like a live event, and continue the discussion in both synchronous and asynchronous modes. Using 3D recording, the students can live through the learning experience over again, work with thresholds concepts, and refine acquired knowledge through discussions.

3D recording of learning and training activities allows producing a new type of content and providing students with new types of experiences. Learners can re-visit their recorded activity in the VW to experience it again, watch their own actions being inside the immersive environment as a third person (another avatar). It is possible to pause the recording, analyze, and discuss the actions. Moreover, this activity can be recorded again together with the analysis and discussion. A series of 3D recordings is called 'virtcast', which is user-generated content, as the process of creating and sharing it is fully automated and simple.

Figure 1. Visiting a 3D recording with yourself-in-the-past in vAcademia

Consequently, we propose that the use of 3D recording in educational context has a great potential. However, this feature needs to be evaluated in real practice and developed further. Theoretical approaches and methodologies also need to be developed in conjunction with the technology, for utilizing the full potential of 3D recording.

Technically, two types of scenarios may be considered. First, after being recorded, any session can be revisited by the same or other learners. All the actions and conversations can be re-experienced and analyzed.

Second, any session can be recorded again while a group of learners is visiting it. As a result, another 3D recording can be created, containing new discussions, questions, and comments (Fig. 3). At the same time, a teacher may let the new group of learners to experience only some parts of the original recording, skipping the other parts (Fig. 2).

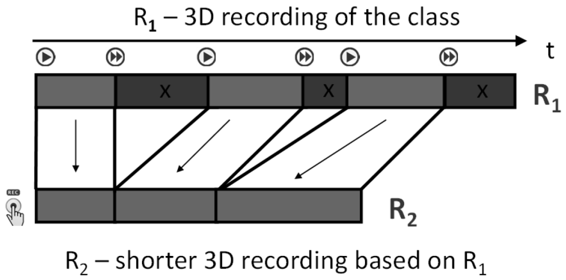

Figure 2. New 3D recording with skipped parts

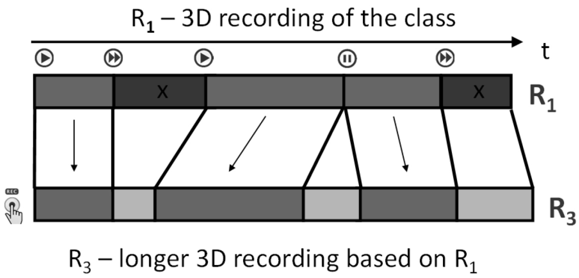

Figure 3. New 3D recording with additional and replaced parts

2.4 Learning scenarios in vAcademia – improving scenario-based role-playing and case-based learning

vAcademia allows many ways of working with learning scenarios. First, part of the roles in a scenario may be played by humans and part by pre-programmed avatars – bots. Second, a learner (or a group of learners) may study the same scenario many times, playing different roles. Finally, the environment may be parameterized, providing several modifications of the same scenario, for example, difficulty level.

Usually, a learning scenario exists as a script and an [virtual] environment/stage, where it can be played. vAcademia may allow implementing learning scenarios as 3D recordings, in which some actions may take place. Something may happen in the environment before the main play or as a pre-recorded part of it, for example, an emergency or an accident. The pre-recorded parts may be played by teachers (humans/actors) and guide learners through the scenario, make them focus on threshold concepts during the live play (Fig. 4).

Some roles of a learning scenario may be played by bots, which is easy to implement in vAcademia in comparison to many other VW (such as Second Life). However, the (key) actions need to be undertaken by the players. In such a way, a scenario may provide a living setting for the players, not just a textual script.

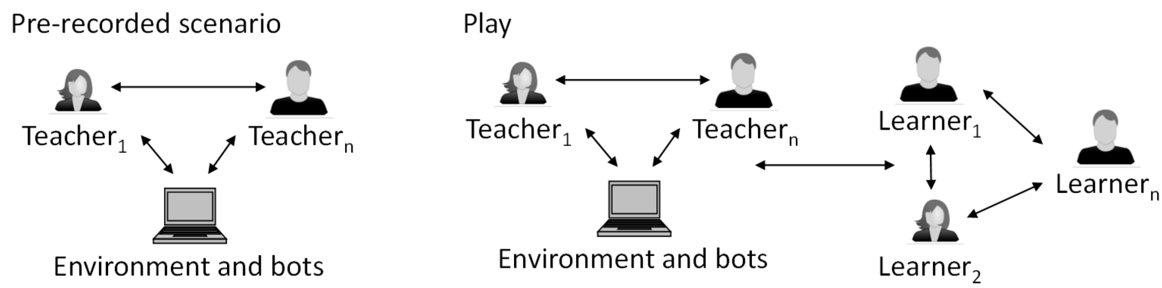

Figure 4. Scenario format in vAcademia

The presented feature and the proposed method can improve learning by providing a convenient way for implementing learning scenarios and allowing learners to work with their recorded trials without limitations.

3. SYSTEMS DESIGN AND DEVELOPMENT APPROACH

In this section, we propose a systems design approach for designing a platform for the education of threshold concepts using virtual reality technologies. From this point on, we will refer to our proposed systems design as ThriVE (Threshold concepts in Virtual Environments).

We propose the ThriVE design will consider technologies such as desktop VR and immersive VR in teaching and learning. Immersive VR such as head-mounted displays, CAVE-like environment (Cruz-Neira et al., 1992) and other immersive installations have attracted industry attention in certain key industries such as for example vehicle simulation and training, scientific visualization, and psychology.

There are numerous systems that can be used to visualize 3D learning simulations, but we propose that ThriVE should explore two types in particular: CAVEs and the 3D desktop technologies vAcademia. As introduced earlier, the CAVE is an immersive projection technology described in (Cruz-Neira et al., 1992) while the 3D desktop technologies are defined as a desktop display system with 3D stereoscopic features. These systems differ in interactivity, navigation, screen size, immersion levels and fidelity levels. There has been little research on the effects of these systematic differences on learning with support of these technologies. Therefore, it will be necessary to compare the capabilities and limitations of these two types of systems. Prototypes of learning scenarios will need to be designed, developed and tested within each of the technology platforms.

This paper largely addresses the theoretical concepts and the design approach to designing a learning platform (that would be represented in a "ThriVE prototype"). However, to give a more concrete example of how this platform might contribute to learning threshold concepts in a particular domain we choose to examine the domain of architectural design more closely.

To help identify threshold concepts within the field of architecture, the research team conducted open question interviews with two experts in the field of architecture. The experts are: a Lecturer in Urban Morphology and Theory, and a Reader in Space and Adaptive Architecture. Both are teaching in graduate programs at University College London.

The theme of "space syntax" was identified as a threshold concept. Space syntax is seen as a very broad theme, the knowledge domain for an entire graduate master level programme. Within the field of architecture, graduate students usually have some degree of professional experience. The experts point out that the students that have mastered the concepts of space syntax make different assessments and decisions as applied to architectural designs. This has been tested in student responses to classroom assignments. Concepts related to understanding space syntax include understanding the impact on changes in: "lines of sight" and "where people are likely to move, gather around objects, meet others". In fact, the integrative way that students think about spaces, tectonics and volumes are all part of a long threshold in architecture, according to the experts. One pointed out that, the students that know about space syntax are more likely to use those concepts in design decisions. The educators further point out that it is easy to distinguish between the students who "get it" and those who do not; e.g., those who struggle with the tools and models. While student can seemingly master the functionality of the tools and models, allowing them to achieve much delineated responses to design questions, the questions in architectural design are sometimes complex and do not have simple answers.

How can the proposed prototype design be used to contribute to the architecture student's learning? At present the students mostly work with visual presentations of their work in 2D. The application of 3D tools in itself offers another perspective that can be helpful in learning. However, to go beyond this, we suggest that a prototype using real-time feedback in the CAVE and using vAcademia in the CAVE would aid students in integrated analysis of complex spatial problems. For example, a scenario might be designed for learning the best design choices. Thus moving objects within the scenario model might change lines of site or axial lines of a virtual build. The prototype would visualize the axial lines (represented as a color line in a simulation) and the lines might move or change color, when objects have been moved. This would give immediate feedback to the student participating in the prototype, and would offer opportunity for learning the integrated meaning of space syntax, based on the student's own actions in the prototype. Student learning could be compared under different conditions such as: fulfilling class room assignment with graphical 2D tools, fulfilling assignment using desktop vAcademia, and fulfilling assignment using vAcademia in the CAVE.

3.1 Systems Design Objectives

The systems design should be informed by the literature review that gives evidence of the learner engagement by use of simulation in learning. However, little research has been performed that evaluates the quality of learning outcomes where using the additional pedagogic constructs of replay and reflection that are possible using 3D technologies. The opportunity for design of malleable learning scenarios, and the usefulness and immersion levels of these VR systems to learners are important in improving the learning experience. Therefore, we also suggest that a theoretical framework for learning threshold concepts in VR systems is needed to inform the systems design. We suggest that learning outcome should be a measure of validation to be tested with prototypes. The evaluation of the prototypes will inform a new cycle of design and improvement.

In brief, the objective of ThriVE system design should be to explore new ways of learning that stimulate and enhance the potential of human creativity, and to support this objective by development of a fully functional (a) prototype for a new way of teaching through VR learning environments. To achieve this, the system design for ThriVE should consist of the following development elements:

1. A conceptual theoretical framework for learning threshold concepts in VR technologies – This framework should consist of the following elements:
    a. Identification of domain specific threshold concepts and design of templates – to inform models of effective learning scenarios in specified learning domains
    b. Design of scenarios that stimulates creative learning – these are reusable discipline-based learning scenarios
    c. Testing learning scenarios and newly designed capability of VR-replay on 3D-modelled learning scenarios – on two VR platforms
    d. Design and testing of quality protocols – for use in design of new learning scenarios
2. A fully functional prototype VR learning environment that will include:
    a. Implementation of learning scenarios prototypes – on two VR platforms to include a set of "VR-scenarios" – that will support the transformative processes of professionals in two different domain-specific disciplines. In particular, we will develop a VR application environment to support threshold experience acquisition in a selected domain. One example is the domain for medical (health) professionals, such as understanding anatomy and physiology in relation to professional practice. A second case domain described in more detail above would be to support creative design for students of architectural design. The selected domains would explore the support of VR for communicative and spatial threshold concepts
    b. Integration of the VR capability of "VR-replay" applications that are newly designed in this project to be functional between the two VR platforms (CAVE and vAcademia)

A prototype based on vAcademia within the CAVE would allow for the exploration of the power of desktop and immersive VR for teaching creativity. Figure 5 depicts an example of a student using both of these VR technologies.

Figure 5. vAcademia in CAVE

3.2 Achieving the Systems Design objective through Integrative State-of-the-art Technology Approach

One strategy to the design of a prototype would be to identify learning situations (identifying key factors) that can benefit from the unique qualities of desktop and immersive VR and design scenarios with these factorsSince its inception in the 1980s PBL has developed in diverse ways worldwide, yet there has been relatively little mapping of its theories, practice or disciplinary differences. This has led to confusion within the academic community about which instantiation to adopt or what will be the best fit for a given curriculum. Merely to list specific and narrowly defined characteristics does not in fact untangle the philosophical conundrums of PBL. Further, PBL is an approach to learning that is affected by the structural and pedagogical environment into which it is placed, in terms of the discipline or subject, the tutors and the organization concerned. Whilst PBL is still undergoing a process of change worldwide, such change has been analysed by few in the field of higher education and Table 1 offers possibilities on offer for using this design.

Approach to Learning	**Organization of knowledge**	**Forms of knowledge**	**Related theory**	**Theorist**	**Role of Student**	**Role of tutor**
Problem-based learning	Open ended situations and problems	Contingent and constructed	Critical pedagogy and social action	Freire (1972, 1974) hooks (1994)	Active participant and independent critical inquirer who owns their own learning experience	Enabler of opportunities for learning
Project-based learning	Tutor-set, structured tasks	Performative and practical	Cognitive learning theories	Vygotsky (1978) Ausubel et al (1978)	Completer of project or member of project team who develops a solution or strategy	Task setter and project supervisor
Problem-solving learning	Step-by-step logical problem-solving through knowledge supplied by lecturer.	Largely propositional but may also be practical	Cognitive learning theories	Vygotsky (1978) Ausubel et al (1978)	Problem-solver who acquires knowledge through bounded problem-solving	Guide to the right knowledge and solution
Action Learning	Group-led discussion and reflection on action	Personal and performative	Change management	Revans (1983)	Self-advisor who seeks to achieve own goals and others to achieve these via reflection and action	Facilitator of reflection and action

Table 1. *Current forms of active learning which may be linked with problem-based learning (Savin-Baden, 2014, forthcoming adapted from Savin-Baden and Major, 2004)*

The scenarios in the learning situations should be designed to challenge the unique qualities of the students target group (e.g., the students' ways of thinking and ways of approaching the phenomenon). By observing students during the activity and follow up by stimulated recall interviews researchers would get a better understanding of how this technology supports transitions through thresholds. Furthermore, by participating in and reflecting on experiences from the intervention the students would gain understanding about their own learning process. The trials would create knowledge about the students experiences, how they think about the phenomena, the troublesome knowledge they experience, the experiences of a threshold, identify different levels and characteristics of liminality, resistance, rupture, moratorium status and ways of overcoming the thresholds. In other words, the objective would be able to identify what helped students, what hindered them, what they did do, and why they did it.

We hypothesize that using the 3D recording feature of vAcademia (or any other resulting prototype) in the CAVE could potentially reveal patterns of becoming aware of one's own reflective learning patterns and deciding to use them consciously. Sequential interviews have been found to reveal this pattern (Boyd and Fales, 1983). The effect on learning of being able to replay one's life-size avatar representation and see one's previous actions would be investigated thoroughly.

The controlled environment allows for running systematic observed and tracked learning sessions. This approach would be to first implement scenarios using CAVE based scenario trials. The testing of scenarios within the CAVE would allow for the measurements of single participants and observations of physiological responses (as indicators of engagement) of participants during trials. This would be done for establishment of baseline measures prior to trials involving collaborative learning among several participants. Multiple participant trials would be possible by running vAcademia in CAVE, so that the participant in the CAVE would interact with other trial participants who would access the trial while using vAcademia through desktop. We would compare learning responses of participants using vAcademia on the desktop and in CAVE. In this way, key features of the threshold concept would be tested on a prototype that is a CAVE version of vAcademia. The prototype design would (with several case scenarios integrated within the platforms) aim to support the ultimate objective for promoting students to overcome thresholds and enable them to identify what creativity in learning means in relation to their individual experiences in transformative processes.

3.3 Systems Design Approach

We suggest the steps forward in systems design and development of ThriVE would follow the phases depicted in Figure 6, from left to right, with parallel activities appearing as vertically aligned. The systems development is recommended to take place using a minimum of two cycles to give opportunity for improvement to the theoretical framework and prototype designs.

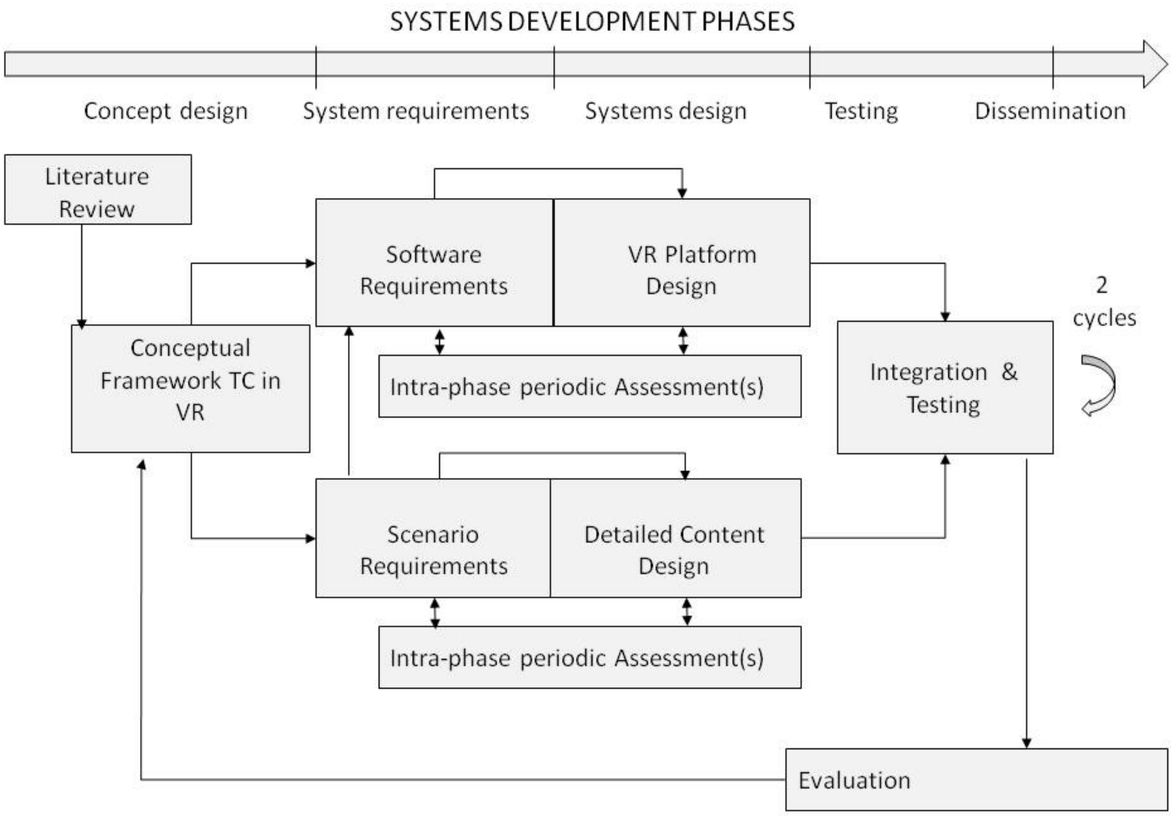

Figure 6. System development phases for development of an application for teaching threshold concepts using a virtual learning environment

The systems development might adopt a design science research method (Hevner, March, Park and Ram, 2004; Spence, 2010). The IT construct of the learning system in this case would be the VR prototypes. Through a cyclical process the prototypes could be developed and provide improvement of the theoretical framework. Ultimately, the goal would to be able to repeat the design of working systems beyond the stage of prototype development. The process of design science research consists of five steps: problem awareness, suggestion, development, evaluation, and conclusion (Vashnavi and Keuchler, 2004). This aligns well with our five phases presented in Figure 6.

5. CONCLUDING REMARKS

A main focus of this paper has been to clarify the research opportunities for teaching threshold concepts using virtual world technologies. Our literature review gives motivation for the design of a conceptual framework and prototypes based on several VR technology platforms. We propose an approach for the design and testing of a conceptual framework and several prototypes. We predict the development of prototypes will give opportunities to further explore new ways of teaching threshold concepts. Our research group will seek to further the realization of these ideas. Through further research we intend to explore questions such as: how do enhancements to the technological environment impact creative development, are some VR-based environment's interfaces too limited for certain tasks, can the same threshold concepts be taught using different VR technology platforms, and are some VR platforms best for a given task. This paper is a first step in this research process.

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