

## Repositories of Community Memory as Visualized Activities in 3D Virtual Worlds

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### Abstract

*In this paper, we propose that visualized activities and experiences created in 3D virtual worlds may provide a new type of learning community memory. We explore how such activities and experience can be captured, crystallized, and reused with this technology in three prototypes designed on two platforms. This approach can support learning communities by addressing the common challenge of acquiring and communicating tacit knowledge that resides in practices and relations developed by the participants. Based on our experiences, we discuss the possibilities and challenges for creating and using repositories of community memory as visualized activities in 3D virtual worlds, outlining a framework for capturing, visualizing, and accessing such activities. The results of our exploration demonstrated that repositories of the 'fluid' community knowledge might be in fact created and used. At the same time, more extensive evaluation and further research are required for developing the approach suggested.*

### 1. Introduction

In this paper, we focus on affordances of 3D Virtual Worlds (VWs) for facilitating collaborative creation of knowledge and the use of community as a means for creating memory repositories. From an epistemological perspective, knowledge resides in and is accessible from these repositories. Knowledge 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 [32]. In a professional development or education, the two types of knowledge are mutually dependent and mutually constituting [31]. 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 choice of 3D VVs is motivated by our intent to explore their possible affordances for conducting interactive activities that can simulate real-life situations and augmenting them with auxiliary tools that do not exist in real life and means for collaborative work with various types of resources [2]. Most VVs allow advanced content manipulation, uploading, creating, and sharing 3D objects and other media, such as text, graphics, sound, and video. 3D VVs have been extensively used for preserving cultural heritage and making the knowledge accessible by implementing virtual museums and reconstructions of artifacts and places [37]. Around 2009, it was estimated that about 300 HE institutions had access to Second Life [35]. Still, the full impact of as well as understanding of learning in virtual environments is relatively underdeveloped [36]. Some studies suggest that 3D visualization can improve learning significantly and assist learners in relating theoretical knowledge to practice [21].

However, a collection of static or even interactive objects and environments do not provide a solid enough representation of community memory. Learning communities may carry and communicate part of their knowledge, both 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 [10, 24], we may see *activity* as a primary source of knowledge development and distribution. Therefore, we focus on visualizing and crystallizing learning community activities.

We have earlier discussed and realized the idea to store community memory as a repository of virtual places that act as crystallization of memories of users and groups, their trajectories, culture and ecology within an organization/community, activities and

cooperation patterns, constituting the shared repertoire [33]. A typical example is a seminar room, with traces reflecting the presentations held there (e.g., agendas, slides, logos). Another example is a visualization of a student science project, containing traces of the students' collaborative constructive activities and elaborations of the ideas behind.

In this paper, we present our explorative experience of crystallizing activities in 3D VWs in different ways, e.g., as traces remained in 3D constructions, as 3D constructions themselves, and as 3D virtual recordings. We explore (1) what knowledge may reside in such captured activities, (2) what is the educational potential of such knowledge, and (3) what technological and methodological challenges and opportunities our approach faces. We exemplify our experience with three prototypes presented in section 3. We discuss how a 3D VW can be used not only as place of enactment, but also as a place of access to various kinds of data to be enacted or collaborated into knowledge by the community members. We believe that the novelty of our research lies in a systematic approach to visualization and crystallization of activities in different types of virtual environments as a source of community knowledge. Our goal is to obtain a different view on the notion of 'crystallized activity' and community knowledge (especially tacit one) in the light of the advances in 3D technology. Therefore, the nature of this study is exploratory.

In order to generate an initial hypothesis, we start with a theoretical background in activity theory, community memory, and threshold concepts, continuing with related work on typology of 3D educational visualizations and ways of capturing activities in 3D VWs. Further, we present results from our projects with different approaches to visualizing and crystallizing community activities. Based on these experiences, we provide a framework for visualizing and crystallizing community activities and discuss the value of this approach from the perspective of activity theory and threshold concepts.

## 2. Background and related work

### 2.1. Activities constituting community memory

In order to better understand the notion of community memory we refer to the seminal work on communities of practice presented by Wenger [41] and the theory behind organizational memory [1]. This rests also on ideas found in activity theory, that links the development of knowledge to action and the use of artifacts [10, 24]. 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" [41]. The collection of such artifacts comprises the shared repertoire and history of the community. Drawing upon the works of Lave and Wenger [22] and Duguid and Brown [7], we describe the learning process and creation of knowledge as characterized by narratives, collaboration, and social constructivism. Narratives are used for the diagnosis of problems and as repositories of existing knowledge, be that tacit or explicit [32]. Narratives also contain the tacit knowledge of a given domain or field of practice, and provide a bridge between tacit and explicit knowledge [25]. Through collaboration in shared practices, knowledge may be created and distributed among the participants. Such a socialization process may give the learners access to the *episteme* or *underlying game* of a discipline, the most difficult knowledge to access [11].

Recent research suggests that 3D VWs may provide a strong sense of space, place, and location [6, 38]. 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 [18]. The emerging place is constituted as a social process in the intersection of human behavior, experience and the materiality of the space available. This understanding led to the idea of virtual places as crystallization of personal and group memories, constituting the memory of the community [33].

Walsh and Ungson propose that interpretations of the past can be embedded in systems and artifacts as well as within individuals through the narratives they may convey [39]. Organizational and community memory consists of mental and structural artifacts [39], but it can also be thought of as processes and representational states [1]. In addition, an integral part of community memory is the histories and trajectories of its members as expressed in narratives represented as the community's shared repertoire.

### 2.2. Threshold concepts

Many knowledge domains contain knowledge components that are difficult to perceive and get for

the newcomers in a community of practice. Typically, there is an asymmetry between the knowledge of the newcomers and experts in the discipline. This asymmetry refers not only to the mastery of skills, but is linked to deeper levels of understanding the discipline or profession, frequently connected to tacit knowledge [32]. The apprentice – master metaphor contains this understanding of the difference. Access to such knowledge is thus of the utmost importance, to the individual to enter into the community, but equally important to the community itself in order to accommodate new members. Land and Meyer have termed these necessary but painful knowledge components for passing *thresholds* that represents a transition in understanding [29]. These concepts in a discipline necessitate a shift in ontology and represent a portal through which the learner will have to pass. While struggling with a new way of perceiving the practices of a discipline, the learner is in a state of liminality before finally grasping that which makes the transition [28].

An increasing body of research from different disciplines have suggested that *the ability to visualize* represents a particular difficulty for many learners. Amongst these disciplines are economics, electrical engineering, the medical disciplines, and biology [9, 19, 40]. The common problem in this body of work described is an ability to perceive unseen forces, patterns and the transition from 2D (i.e. on paper) to 3D (i.e. “real life”), such as in anatomy. 3D environments may be perceived as an interim stage in such a process towards deeper understanding, from surface learning to deep learning [5, 12]. By providing a landscape in which to move and interact, the learner may approach the understanding more easily. Crystallized activities and especially the recording and replay functions afford the opportunity to uncover what is hidden to the learner.

### 2.3. Capturing activities in 3D Virtual Worlds

3D VWs provide a unique set of features that can be used for conducting various activities, such as low cost and high safety, three-dimensional representation of learners and objects, interaction in simulated contexts with high immersion and a sense of presence [27]. Capturing such activities is a complex task from the technological point of view, as part of the information is usually lost. Using other technologies, such as video recording of face-to-face activities or recording of web conferences is not as complex. However, these technologies change the context of activities. They do not provide the same level of immersion, a possibility for collaborative

work, or a method for further developing the ‘crystallized activities’, except for annotating them.

Currently, 3D VWs are also used for capturing activities, but usually only as ‘flat’ 2D video, which eliminates many advantages of the technology, such as sense of presence [27]. For example, this approach is used in Machinima – collaborative film making using screen capture in 3D VW and games [4].

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. MASSIVE-3 supported overlaying real-time virtual environments and previously captured ones [17]. CAVERN supported recording and sharing of an avatar’s gestures, audio and surrounding environment [23]. Asynchronous Virtual Classroom allowed learners to watch a video image of a certain lecture and to control it, while software agents were playing some of the displayed participants and created a presence effect [26]. Later, N\*Vector developed approaches to support annotations for asynchronous collaboration in VR, including an annotation tool, an email system, and a streaming recorder to record all transactions that occur in a collaborative session [20].

More recently, the Event Recorder feature was implemented within the Project Wonderland (later, Open Wonderland™). Event recorder provides an implementation of the 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 activities in 3D VWs or other similar environments. As presented above, creating content out of synchronous activities is an important in-demand task. However, there is a clear possibility for improvement, as the application potential for community memory repositories was not yet realized.

### 2.4. Typology of 3D content and visualization means

The Typology of 3D Content and Visualization Means is a characterization framework. It suggests describing a 3D construction along two dimensions: virtual exhibits (content itself) and visual shell (content-presentation form) [13].

Virtual exhibits have three main categories: text, 2D graphics and multimedia, and 3D visual symbols. An additional dynamic category considers how the virtual exhibits are presented by the authors. 3D VWs allow presenting information in different modes including installations and “dioramas”. Virtual

exhibits can have different degrees of interactivity, from triggering simple events to complex scenarios.

By visual shell in a 3D VW, we mean a way of organizing, presenting, and structuring content, for example, using a certain metaphor. Although the content itself often has higher priority than its presented form (a shell in this context), these two concepts are interdependent and complement each other (being a duality). A visual shell can be described using three dimensions: aesthetics, functionality, and expressed meaning.

Aesthetics of a shell plays an important role in enhancing motivation and triggering creativity of both participants of visualization process and visitors. Functionality is the ability of a construction (or a part of it) to perform a certain task or function. It is often in conflict with the aesthetics of visualization. This may include elements such as furniture, doors, stairs, lighting, sound, and various 'fancy' items being obstacles, complicating navigation and diverting attention from the actual content being displayed. Visualizations with simple structure are easy to comprehend. Such simplicity is often achieved at the expense of less elaborated aesthetics.

Expressed meaning is the symbolism contained in the overall design of a construction and in the details. This aspect of meaning might be in conflict with aesthetics and functionality since creating realistic and meaningful constructions often requires a significant amount of effort and planning. However, the expressed meaning contributed to a better understanding of the content that was inside (for example, by creating associations).

Choosing a suitable presentation form for a topic is about finding a balance between aesthetics, meaning, and functionality of the visual shell as well as ways of displaying the virtual exhibits.

### 3. Prototypes

Designing and evaluating the three prototypes presented in this section, we explored the affordances of 3D VWs for capturing learning activities and storing them as part of community memory.

#### 3.1. 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 [34]. A library of pre-made 3D objects, scripts, and textures could allow

concentrating more on the 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 prototype 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. 1).

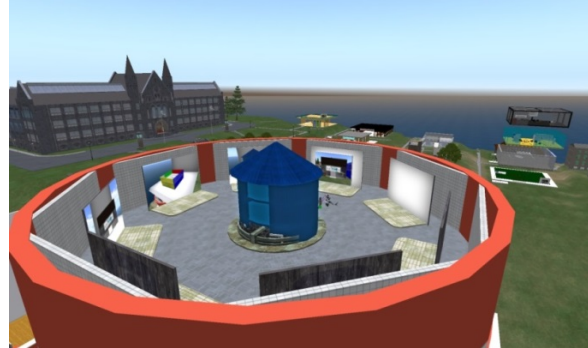


Fig. 1. Virtual Gallery prototype

In two other studies in 2010 [14] and 2011 [15], we collected student feedback on their experience of using VG and its functions. The students were given a task to visualize (as a 3D construction and an activity) a research project or one of the course key concepts. 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. The second lab could take appropriate actions thanks to awareness mechanisms. The visualization was later stored in the VG.

The studies were conducted with 25 and 37 students working in groups of 3–5. None of the students had previous experience with the platform in both studies, but they received pre-training. In addition, most of them were fourth-year computer science students, which should be considered when evaluating the results. In both studies, we collected data from the direct observation of students' activities, virtual artifacts (3D constructions and chat log), and feedback in a form of group essays in 2010 [14] and group blogs in 2011 [15]. The data were analyzed using constant comparative method [16].

Analyzing the results, we found that most of the student groups stressed the importance of having access to previous students' constructions to have inspiration for their projects. Some of the groups

stated also that they get additional motivation from exhibiting their construction for other people. The realism of the buildings in the virtual campus was recognized as important for supporting community and providing a shared sense of place.

### 3.2. Sharing project visualizations 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 environments and engaging the public [14] 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 prototype 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 (Fig. 2).

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 [14] 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.



Fig. 2. Virtual Research Arena prototype

### 3.3. Training medical personal using 3D recording in vAcademia

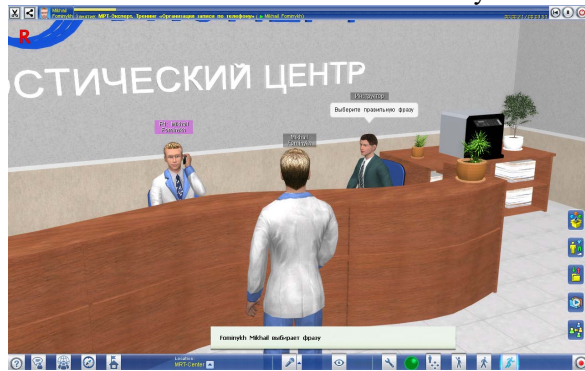
The prototype implements a training environment for medical center managers. It is implemented in vAcademia 3D VW (<http://vacademia.com/>). The most distinctive feature of this platform is 3D recording, which allows capturing and replaying activities in a given location in the VW, including positions of the objects, appearance and movement of the avatars, media contents, text-chat messages and voice communication. A user can attend and work inside a recorded activity, not just view it as a spectator. In addition, any recorded activity can be attended by a group of users. A new group can work within a recorded activity and record it again, but with their participation [30]. Considering that such features of the vAcademia platform very useful for capturing traces of activities, storing and modifying them, we selected this platform for another prototype.

The prototype is based on a typical scenario – answering phone calls. The basic training session is intended for a single user. The trainee answers a call from a potential client (pre-recorded voice). The trainee is offered three options written in text which an assisting bot is offering. 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.

Even though the training session if made for 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. 3) 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.



**Fig. 3. vAcademia training center prototype**

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, than 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.

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 and the company – to have multiple examples (best and worst cases). It would provide an opportunity to identify what aspects of the learning outcomes that are the most difficult to arrive at for the learners. This insight could again be fed into a redesign of courses and training programs. 3D recordings can be modified and annotated by experts, for example including theoretical explanations (right in the context – inside the 3D recording).

An important part of this training is to develop the professional sensitivity of the learners, and to develop 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 [8]. The notion of *care* is also complicated since it challenges the learner’s preconceptions with the “messy realities of practice” [3]. This change in perspective represents a threshold concept.

## 4. Discussion

Our experiences show that crystallization of collaborative activities and 3D visualization enriched the reflective dialog in the communities with innovative expression forms and contributed to creation of a shared repository of community knowledge. In particular, findings suggest that 3D VWs allow storing community memory directly in the form of crystallized activities, something that allows the users to grasp complex concepts and access tacit knowledge.

The 3D virtual environments may thus be a valuable add-on and contribute to the educational repertoire. By allowing learners to replay and comment, alone, with peers and masters, the apprentice role may be more easily transcended. The opening of such learning situations enables both the apprentice and the master to mutually share their understanding of the topic at hand, thereby contributing to the memory of the community. We suggest that the distance of the replay situation offers an opportunity for reflection and dialogue not found within a traditional learning situation.

In order to be able to create and analyze such activities and a combine them into a community memory repository, we developed a characterization framework. This framework is based on our experiences with VG and VRA prototypes presented above and builds further on the Typology of 3D content and visualization means [13] shortly presented in Section 2.4. Previously, we focused mostly on static 3D virtual exhibits, possibly with some dynamic components (such as a role play). However, our experiences show that this approach does not take fully into account the role of activities in learning communities, does not describe activities enough, and therefore needs to be revised, hence the new framework. Along this framework, we discuss different ways of visualizing activities and associated challenges. The more general nature of this framework will allow combining both static and dynamic elements, encompassing the duality of the participation and reification processes.

### 4.1. Contents and presentation forms of crystallized activities

We start categorizing crystallized activities with the same dimensions as for static visualizations, such as virtual exhibits and virtual shells, elaborating with new dimensions and comparing how activities can be captured in different virtual environments.

**4.1.1. Content of crystallized activities.** In addition and as opposed to static 3D visualizations,

we introduce the dimensions of dynamism, explicitness, and complexity.

*Dynamism:* Crystallizing an activity supplies it with qualities of passive content e.g., when a project work ends up as a finished construction. This allows activities to be operated like any other content (as we did with the Virtual Gallery and 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 3D recording feature (e.g., overlaying multiple recording of the same activity, as was the case with the call center example). It can also be addressed methodologically by developing approaches for retrieving knowledge from crystallized activities or by performing collaborative work in crystallized activities, for example making a science project presentation ‘active’ again by performing a role play / seminar in the corresponding construction or analyzing / discussing a 3D recording. This shows that dynamism is not a discrete, but a continuous quality, with transition between states, stretching on a scale from an already recorded activity to the activity process such as on-going projects or role plays.

*Explicitness:* This quality describes to what extent a crystallized activity and its components can be experienced in the same way as a live activity. For example, activity might be presented explicitly in the form of a 3D recording like in vAcademia or implicitly in the form of traces left. Describing explicitness becomes especially important as one of the purposes for crystallizing activities is visualizing trajectories of individual users, and therefore ownership management, privacy, and copyright issues should be considered.

Managing ownership rights in Second Life is often in the conflict with flexibility of collaborative constructing and storing the content, requiring certain compromises, as our experience with the VG prototype demonstrates. However, if necessary, the implicit activities (3D constructions with activity traces, as in VG and VRA prototypes) can be technically decomposed into 3D objects that still have meaning and belong to certain users or e.g., visualized projects. However, the explicitly captured collaborative activities (3D recordings as in vAcademia prototype) cannot be decomposed in this sense, like e.g., a participant cannot be removed from a recorded round-table discussion. In this light, managing the ownership of captured collaborative activities (and hence trajectories of community members) is even more problematic, as they typically include avatar movements and voice communication of several people.

*Complexity:* Recorded or crystallized activities can be seen as elements of knowledge. At the same time, each of such activities may consist of numerous elements (such as avatars, 3D objects, communication streams, annotation notes, and media contents). Automation of the analysis of such data and retrieving valuable information from a repository consisting of such complex activities is a challenge. The difficulty lies in retrieving the knowledge 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.

**4.1.2. Presentation forms of crystallized activities.** The three dimension of describing presentation forms of the ‘content’ (aesthetics, functionality, and expressed meaning) acquire additional qualities and appear in a new perspective when describing crystallized activities.

*Aesthetics* of a crystallized activity describes what makes it appealing for the visitor. Compared to a static 3D construction, the aesthetics of a crystallized activity may include additional qualities that make it generally appealing, and not necessarily from the artistic point of view. Describing and designing the aesthetics of activities to be crystallized, a wide range of perspectives may be considered from human-computer interaction to dramatic art.

*Functionality* of a crystallized activity describes how it is operated or used after being captured. Capturing activities as 3D recordings in vAcademia is rather straightforward and explicit, allowing direct publication and replay/revisit. Nevertheless, using crystallized activities this type may benefit from certain structure or guidance, such as pre-recorded scenarios and assessment mechanisms. Using activity traces captured in the VG and VRA might require more intense management by scaffolding and guiding community members through the community repository, organizing collaborative activities and providing means to support them (such as pre-made scenes and various authoring/building tools in the VG), directing participants through a series of stages.

*Functionality* of a community repository containing crystallized activities describes how such activities are operated and managed. Crystallized activities can be collected in certain knowledge domain, tagged, and made available for combining

into chains or individual learning trajectories depending on the learning goal and the initial knowledge of the student as ‘learning objects’. In such a manner, a community memory of fluid tacit knowledge may become a practical learning tool.

Indexing and annotating of such a repository is important, but complicated due to the fluid nature of the learning communities and the ambiguity of the content which might be interpreted differently depending on the context and the background of the visitors. Due to this context dependence, it is not always possible to store and transfer crystallized activities between different platforms. Even when technically possible, the 3D content in the repository might lose its context and connections. For example, when ‘storing’ a virtual project presentation in a repository without the surrounding Research Arena that gives proper meaning to it. This challenge can be addressed by developing a recording standard which would make crystallized activities a more common element of community repositories and constitute a step towards solving the general interoperability issue between 3D VWs.

Even though 3D VWs are becoming more widely used, they are not as easily accessible as e.g., web resources. Most of the present day individuals need to learn how to use this technology, but also there is still a technological threshold of accessing them due to the bandwidth and computational resources required by 3D visualizations. This might make it less suitable for certain communities with limited access to Internet such as developing countries. At the same time, screen-capture videos and protocols of past activities or streaming in real time can be made easily accessible on the web and serve as doors leading to experiencing activities themselves.

*Expressed meaning* of a crystallized activity is the knowledge that resides in it. Such knowledge is often tacit implying that it is difficult to represent it explicitly e.g., with traditional forms of repositories. While a static 3D construction could communicate a message or convey a certain idea, a crystallized activity can carry a story or an experience.

#### **4.2. Learning potential of crystallized activities**

Discussing crystallizing activities in terms of the content – presentation form, it is important to keep in mind the duality of this process, corresponding to the duality of participation – reification processes [41]. Capturing the process of ‘participation’ as crystallized activities can be seen as ‘reification’, but at the same time, it keeps the traces of the original process and allows multiple reifications.

Since the idea of threshold concepts is closely tied to the entrance into a community of practice and getting access to the full knowledge ecology, the affordances of 3D VWs give several possible entries into these knowledge repositories. Immersion into well-designed learning environments in itself gives access to the full complexity of how a profession is challenged and enacted. Narratives prove the bridges between tacit and explicit knowledge, while at the same time representing the collective history of that community. The usefulness of narratives increases when they are stored as crystallized immersive activities and especially as explicit 3D recordings.

Since the focus of this research is on learning communities, the findings presented here mostly apply to educational situations in 3D VWs where learners co-construct their environment collaboratively, leaving traces of their activities. Crystallized activities approach is less relevant for pure simulator-based training, e.g. in the classical case of a pilot simulator, primarily targeted at single users where community involvement is not essential.

### **5. Conclusions and future work**

In this paper, we report an explorative study on crystallization and 3D visualizations of collaborative activities in 3D VWs. As a result, we have arrived at an initial hypothesis that a collection of such crystallized activities is capable of representing community memory, allowing community members to acquire and communicate tacit knowledge that resides in practices and relations developed by the participants. The hypothesis is to be tested additionally in future studies.

The suggested framework for using 3D VWs as platforms for community memory repositories and for creating 3D visualization of activities acts as concretization of his hypothesis. It is in its early phase and will be extended and further refined by adding additional cases to our analysis. At this stage, the major contribution of this work as we see it is a redefinition and extension of the notion of ‘crystallized activity’ (originally defined by Wenger [41]) in the light of the advances in 3D technology. This approach will allow us to discover new ways of understanding and supporting learning communities.

Enactment and participation, complemented with narratives, visualizes aspects of the knowledge of a discipline or profession that is hard to arrive at through traditional training and learning facilities. The use of 3D VWs suggests that learners may benefit considerably from the use of the approach suggested in this paper. At the same time, we have identified a number of challenges associated with



creating and using community memory repositories consisting of crystallized activities.

There is still a need to explore further the affordances of 3D VWs and other virtual reality technologies for supporting such 'fluid' repositories of community knowledge as well as developing methodologies for managing them. This approach has also a number of limitations. It is therefore important to take into account the social and interdisciplinary nature of such repositories, the different types of knowledge they contain, and the context of use. This constitutes yet another direction for future work.

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