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3D virtual world BPM training systems: process gateway experimental results

Michael Leyer[1], Ross Brown[2], Banu Aysolmaz[3], Irene Vanderfeesten[4], Oktay Turetken[4]

[1] University of Rostock, Rostock, Germany
michael.leyer@uni-rostock.de
[2] Queensland University of Technology, Brisbane, Australia
r.brown@qut.edu.au
[3] Maastricht University, Maastricht, the Netherlands
b.aysolmaz@maastrichtuniversity.nl
[4] Eindhoven University of Technology, Eindhoven, the Netherlands
{i.t.p.vanderfeesten, o.turetken}@tue.nl

Abstract. It is important for companies that their operational employees have profound knowledge of the processes in which their work is embedded. 3D virtual world environments are promising for learning, especially for complex processes that have deviations from the standard flow. We design a 3D virtual world process training environment to improve process learning, particularly for complex processes with alternative flows, represented with gateways in process models. We adopt the method of loci, which suggests the mental traversal of routines for improving learning. Our experiment with 145 participants compares the level of knowledge acquired for a sample process with our 3D virtual world environment and a 2D depiction. We found that the 3D virtual world environment significantly increases the level of process knowledge acquired across the typical gateways in processes. Our results contribute to our understanding of how individuals learn knowledge of processes via 3D environments. Practitioners are encouraged to invest in 3D training systems for processes, since these have to be set up once but can be used in a scalable way for a number of employees.

Keywords: Process training, process model, virtual worlds, gateways, experiment.

1 Introduction

For companies, it is important to ensure that employees have a proper knowledge of organizational processes to execute them in an efficient way. Employees knowing the processes they are working in have a better sense on how their work is embedded and invest more time and effort in coordinating with their colleagues [1]. However, such knowledge is often lacking among employees, hence, organizations need ways to enable their employees to get this knowledge [2].

Typical methods used in organizations to make operational employees (employees without leading functions who work in executing operational processes) acquire process knowledge include providing process models before or during operations, organizing training sessions, and lately using technological instruments such as augmented reality glasses [3]. There are difficulties associated with these learning methods, such as process models often requiring too much cognitive effort [4], or augmented reality glasses and trainings being costly and not scalable. Thus, organizations would benefit from alternative training methods to establish process knowledge.

Knowledge acquisition is specifically difficult for complex processes having deviations from the standard flow, which can be different in every execution of the process [5]. Deviations, such as exclusive paths or parallel activities, are represented by gateways in process models [4]. Although process models are widely used in organizations for many other purposes [4], the high cognitive effort required to investigate the models hamper their use as a knowledge acquisition medium for employees with diverse backgrounds.

One promising way to foster better process learning for employees is to use alternative visualizations for process models [6]. While there has been extensive research on finding a better way to visualize processes, these efforts are mostly on using different notations and representations in a 2D-environment [6]. 3D, however, could provide a better and more realistic experience of processes since humans have difficulties to attach the abstract procedural knowledge to real world objects and experiences [7, 8]. Indeed, drawing upon the evidence that is mounting for the abilities of 3D spaces as engaging educational systems [9], we see that there is great potential in the use of 3D virtual worlds (VWs) as visual examples of process constructs in a comprehensive training system for processes.

In this study, we aim to investigate if 3D VW visualizations help to learn processes better across different gateways, since they are a major cause of complexity in process models. For this, we develop a prototype process training environment using 3D VWs. We use the method of loci for designing the environment, which suggests the traversal of the same routine for improving the learning in an imagined environment, in our case VWs [10].

In addressing the research goal, we conducted an experiment with 145 graduate students. For the experiment, we used 2D and 3D representations of a common organizational process. The results indicate that 3D VWs can improve the acquisition of process knowledge related to linear connections and flows with gateways. In contrast to our expectations, no specific learning improvement has been identified for the OR-gateway, which is assumed to be the most complex, thus the most difficult to learn.

The remainder of this paper is organized as follows. First, we present the underlying theoretical background and deduct our hypotheses. Second, we describe the experimental design. Third, we present the results regarding the sample and hypotheses. Fourth, we discuss our results together with implications and limitations. Finally, we conclude with an outlook on future work.

2 Theoretical Background

2.1 Memory and 3D Virtual Worlds

Via mental or physical actions, humans acquire knowledge and contextual information about the task being performed. This has inspired learning approaches applied in educational settings that draw upon situated learning theory [11] positing that education and training works best when the knowledge is learned in the context of where it will be used (situated), facilitating recall of specific activities primed by the correct context. In addition, there has been extensive research on the role of context in recall and recognition [12, 13] under a number of contexts such as cued recognition and forget scenarios. These studies suggest that the brain uses the 1-2 seconds in a recall task to store the existing contextual information [14], indicating that viewing scenes in a VW environment may utilize context effects without any the for lengthy viewing.

Several knowledge acquisition and training approaches utilize the method of loci [15, 16]. The approach requires the laying down of memories of visuospatial routines that are later utilized to remember information by visualizing the traversal of the same routine through the imagined environment [10]. This has been shown to be an effective method for mnemonic memorization of information from behavioral studies [17], with recent work showing its effectiveness in modifying physiological network structures in the brain to enhance recall [10]. Similar brain training effects are enacted by the viewing of 3D VWs on computers, viz. the human brain undergoes similar changes in the hippocampus as it would when moving in a physical reality, even without moving the body, just from visual input alone [18].

Evidence comes from a number of experiments performed that measure the effects of embodied context on memory. For example, airport check-in processes are better remembered with the use of 3D VW representations than using 2D diagrams [8] and better again when using virtual reality [19]. The findings from previous studies support the potential benefits of VWs for BPM training, as activity sequences are an important knowledge in processes [20]. Such a situated approach should yield good process training results due to aiding recall of task sequences.

VWs are an interactive technology whereby the computer synthesizes a 3D interactive reality, which is "a synchronous, persistent network of people, represented as avatars, facilitated by networked computers" [21]. These VWs may be used via immersive interfaces, such as virtual reality head mounted displays. The use of immersive embodied movement within such VWs has been shown to be superior for training purposes [22]. These results all indicate that memory recall and language processing in such environments is strongly affected and may indeed be greatly improved via the rich stimuli provided. [8] found that, in an A vs. B test of 64 participants in a process elicitation scenario, compared to a normal process editor, users of a 3D VW provided more correct activity enumeration and naming, and showed evidence of increased confidence in the results, due to less time spent editing the resultant model.

This leads us to conclude that the 3D VW could be used to impute into the participants the memories required in a process training scenario, based upon an abstract process model. The use of method of loci is relevant for designing visuospatial routines of activity flows in VWs. We expect that memory enhancing effects will occur, viz. participants will remember more elements from the process model, and that they would be faster in the process of remembering the information.

2.2 Knowledge Structures of Processes

Processes consist of activities that are connected to each other [4]. The connections define how the elements (activities) are or can be executed in a certain order. Such sequences can be straightforward, i.e., there is always one activity followed by one and only one other activity, or there is a network of activities that allows for various options including parallel or alternative flows.

It is not feasible for the efficiency of process execution that employees look up the underlying process model constantly [2]. Employees need to acquire the knowledge structure of processes they are working in. Such knowledge enables employees to align the execution of their activities in accordance to the other activities in a process and in this way leads to a higher efficiency in process execution [23]. The essential knowledge for employees to foresee the overall process and align the activities is which other activities exist and how they are related to each other rather than how every activity is performed [1]. Thus, the connections between activities as well as dependencies that define the order in which activities are to be performed need to be learned. The control flow logic indicated by such connections can be ambiguous, i.e., an activity may always follow another activity or one of the many alternative activities can follow. Specifically, divergence and convergence of the control flow logic for decision points and parallel tasks create additional cognitive load, which hinders a proper formation of knowledge structures [24].

2.3 Hypotheses

In this study, based on the method of loci, we argue that VWs can be used as an effective way of acquiring knowledge structures of processes [18], since processes are composed of sequential activities related to each other via a set of attributes such as the action, role, and information. By using visual cues of process elements in a real-like space and incremental execution of process steps primed by those elements, VWs can enable the learners to gain experiential memories of processes. Thus, presenting the processes in the form of visuospatial routines with visual cues of process elements should improve learners in acquiring process knowledge of interconnected activities in general. However, we need to distinguish between different connections among activities due to the use of gateways. This is because the knowledge structure to be acquired is different when different gateways are used and the VW needs to be designed differently to show the flow alternatives represented by the gateways. The first goal of the VW is to invigorate the transition between one process activity to another. Thus, as a first hypothesis, we focus on the impact of the VWs for acquiring knowledge of activities directly following each other:

H1. A 3D VW representation of a process leads to better results compared to a 2D representation in identifying direct connections between activities.

The complexity of a process model induced by gateways is among the most influential factors of process model comprehension [5]. Three gateway types are commonly used in process models: XOR (to cause a flow to two or more mutually exclusive paths), AND (to depict two or more paths that can be executed concurrently), and OR (to trigger the execution of one or more paths) gateways [4]. Since these gateways cause alterations in the order of activities in a way that requires the semantic interpretation of the gateways rather than being directly observable from the model itself, they create additional cognitive load [25]. Such extra cognitive load is a major barrier in the formation of knowledge structures of the complete process [26]. VWs can help to overcome the difficulties associated with gateways by depicting such routines in a more representative way, explicating the meaning of the control-flow logic by borrowing real-life concepts and merging them with environment capabilities. Accordingly, we define the following three sub-hypothesis for each gateway type:

H2. A 3D VW representation of a process leads to better results compared to a 2D representation in identifying XOR-connections between activities.

H3. A 3D VW representation of a process leads to better results compared to a 2D representation in identifying AND-connections between activities.

H4. A 3D VW representation of a process leads to better results compared to a 2D representation in identifying OR-connections between activities.

The current body of knowledge in the area of process model understandability suggests that the models with OR-gateways are more difficult to understand than those with XOR or AND-gateways [27]. This can be attributed to the number of mental states that a reader of a model has to build for each gateway in order to understand the control flow of a process. An OR-gateway creates more mental states than an XOR or AND-gateway [28]. Therefore, using an OR-gateway increases model's complexity, which in turn hinders its understandability [29]. In connection with this, OR-gateway is associated with high error rates in process models [30]. Accordingly, any means to enhance the comprehension of OR-gateways can have more potential to improve the knowledge acquisition of a process. With traditional process modeling notations, it is difficult to implement visual measures to illustrate the logic behind this gateway and alleviate the high cognitive load associated with it, while a VW environment can be used to explicate its semantics. To gather empirical evidence for this contention, we advance the following hypothesis:

H5. The effect of a VW representation of a process regarding OR-connections is stronger than with other connections.

3 Research Design

3.1 Process Used for the Experiment

For the evaluation, we selected an example process, issue management, which is about dealing with a problem in an organization from its identification to resolution. The complete process model of the selected process in BPMN notation is shown in Fig. 1. This process model depicts the activities performed by the roles Requestor, Ticket Manager, Program Manager, and Developer in an organization when a problem is identified for a corporate IT system. The process consists of 14 activities connected with different gateway types, two IT systems, and 14 information elements.

This process is selected and tailored for the purpose of the experiment for the following reasons. First, it is common in organizations and valid for various domains [31]. Second, the process concepts do not bear technical and domain-specific knowledge. Hence, they are understandable by a wide audience. The process model is designed based on several real-life issue management example processes, and incorporates constructs that makes it suitable for the evaluation of our hypotheses. Therefore, the process model includes divergence from the linear control flow by a decision point indicated by an XOR gateway (the activities of *Register problem as regular* and *Register problem as urgent*), a parallel activity sequence enabled by an AND gateway (the activities of *Prepare verification checklist* and *Develop problem resolution plan with Ticket Manager*), and lastly, an inclusive decision point with an OR gateway (the activities of *Verify problem resolution* and *Verify problem resolution and implementation of plan*). The three different gateways are not combined but only used on the main flow of the process (e.g. an XOR gateway is not placed in one of the parallel paths after the AND gateway). Though this may limit the representability of the example process for real life models, we aimed to control the complexity of the VW and measure the impact of the environment separately for each gateway type.

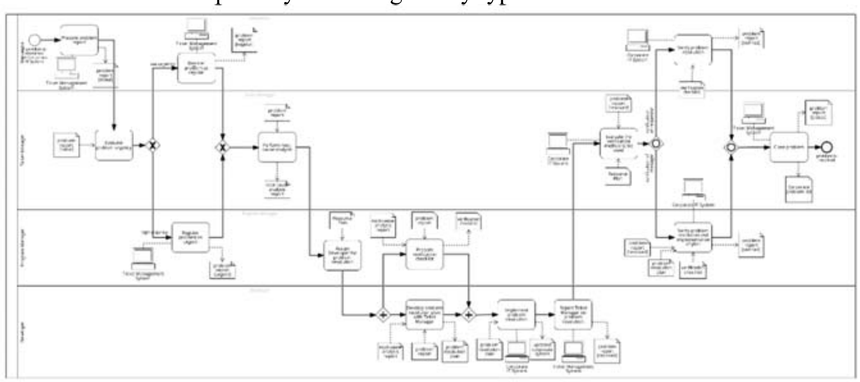

Fig. 1. Example issue management process model used in the experiment.

3.2 Design of the Training Environment

In this section, we describe how we designed the environment to reveal the benefits of VWs for process training [1]. We first start with describing the design to represent a single activity in the VW together with its related elements, then the flow between two activities directly connected to each other followed by the specifics for each gateway type.

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[1] The environment can be downloaded from the following links:
For Windows: http://www.aysolmaz.com/ProbResInfo1Win.zip
For Mac: http://www.aysolmaz.com/ProbResInfo1Mac.zip

Representation of an activity and its related elements. Following the method of loci, we use the VW environment and the role performing the activity in the form of an avatar to trigger the creation of experiences in a VW as it happens in the physical world [10]. The whole office space and the area in which the activity is performed provide a spatial cue for the users of the training environment [32]. The avatars of the roles create the visual context. The same avatar is depicted when a role is engaged in another activity, and the same desk space is used for the individual tasks s/he performs. In this way, the concepts of visual context and spatial location are used to embody real life concepts and implement visual priming to enhance recall [14]. Other process elements such as IT systems and data elements are represented in an abstract form based on BPMN-style notational elements, since these elements do not have any physical discriminatory characteristics. The type of the activity is identified based on the action indicated by its label and the connected process elements. The space in which the activity is performed is set up based on the activity type (e.g. a meeting room or an office desk) [33].

Flow between two directly-connected activities. The flow between two activities is depicted by a camera moving along in the office space from the location in which an activity is performed to the next one. An example can be seen in Fig. 2. When the camera approaches the next activity in a third person view, the activity is red (left), indicating the status as *ready to be executed*. When user interacts with the system by clicking, the status is first updated as *being executed* in amber, and then *completed* in green (right). With the next user click, the camera is moved to the next activity. In this way, the perception of process flow is warranted in a combined stream of activity status and activity changes, triggering the creation of episodic memories [34].

Fig. 2. Example of steps for the representation of alternative flows

Alternative flow with an XOR gateway. An XOR-split is a depiction of a decision point and possible alternative flows based on the given decision in the process. For example, *Evaluate problem urgency* is a decision activity, which leads to a decision of low or high urgency. Given the decision, either the upper activity is executed by the role *Requestor*, or the lower one by the *Program Manager*. The process modeling notations lack the ability to inherently represent what the gateway notation means since they use abstractions. Thus, the novice reader relies on the illusory inference to deduce meaning from the symbol [35]. However, VWs have the potential to explicate the flow logic underlying the gateway by harvesting the features of visual priming to physical form and non-physical representation. Exploiting this capability, we invigorate the alternative execution of two activities as in Fig. 2. The two office spaces and roles are shown side by side to allow for the perception of two related activities. The exclusiveness of activities are depicted by initially showing one of the activities as executed, then, with a move of a camera similar to activity transitions, the activity statuses are reset and the alternative activity is shown to be executed. Then, the view switches to a single camera to indicate the convergence of paths and flow of the rest of the activities. The use of BPMN-like gateway symbols and arrows further support the explication of the semantic depicted in physical form.

Parallel flows with an AND-split and join. The AND gateway after the activity *Assign developer for problem resolution* in Fig. 1. divides the flow into two, which leads to activities that needs to be finished before the rest of the process can continue. Thus, our environment design again exploits the depiction of related activities side-by-side with two cameras in the VW, similar to Fig. 2. Initially, the office spaces related to two concurrent activities are shown side by side. With each user click, the activities change status together, first both turning to *being executed*, and both *completed* at the end. Then, the camera returns back to single view and the process continues with the next activity.

Inclusive alternative flows with an OR gateway. Among the gateways in process modeling, OR gateway is known to be the most error-prone and difficult to comprehend due to its ambiguous semantics [5]. Accordingly, we expect the highest benefit from the training environment, since it is possible to disentangle the ambiguous semantics of the OR-gateway. Similar to the approach in the other gateways, two camera views are provided side by side for the two activities in the issue management process. Through user clicks, the possible flows of only one of the activities, only the other activity, and both activities are represented consecutively. Since the OR gateway enables the execution of activities exclusively or in parallel, all three options for two activities (only one or the other or both are executed) are depicted in the VW.

3.3 Measures

To analyze if a better formation of knowledge structures can be achieved by means of the designed training environment, we employed a questionnaire to measure how accurate the participants are in remembering the process using the procedure described by Leyer and Strohhecker [26]. Participants received a number of questions each asking for the correctness of the connection between a pair of activities. Of these pairs being presented, 16 were correct and 17 were wrong pairs to avoid random guessing. We counted the number of correct answers for identifying the 16 correct relationships and not rating false ones as correct which resulted in a percentage for each participant. All questions were also characterized by their gateway type according to the process design. The number of questions per gateway are as follows: (1) XOR-splits: 9, AND-splits: 6, OR-splits: 9, No splits: 9.

We additionally used questions to evaluate the cognitive profile (through the Cognitive reflection test (CRT) [36] and Global local thinking style (GLT) test [37, 38]) of participants. This was followed by control questions regarding perceived difficulty, interest, prior modeling experience, job experience as well as age and gender.

3.4 Participants and Procedure

The experiment participants were graduate students in the domain of engineering. These students were enrolled in the same master level course on business process management (BPM), where they voluntarily participated in the experiment. As a motivation to participate, the students were offered 0.5 bonus points (out of 10) to their final course grade. Among 190 students, 145 participated (76.3%) reporting an average interest of 5.7 (SD: 1.97) and a perceived difficulty of 4.07 (SD: 1.97) (Scales 1-9). 69.7% of these participants are male and 30.3% female. Participants' average age is 23.2 years (SD: 1.84 years).

There were two experiment groups: one group received the 2D PowerPoint representation of the issue management process and the other one the 3D VW process visualization. Participants were randomly assigned to a group.

When starting the experiment the participants received instructions on their task. Next, they were presented with the first process visualization (either 2D or 3D depending on their experiment group). The number of slides and 3D-representations was equal to ensure comparability of results. After studying the process through this representation, the students received a questionnaire that consisted of two parts as described in the measurement section: a) questions on their knowledge structure of the issue management process and b) questions to evaluate their cognitive profile and to control for other potential influencing factors.

Finally, participants were shown the other representation of the issue management process to allow for a further robustness check in comparing both versions.

4 Results

Table 1 shows the differences between the scores of the 2D vs. the 3D VW and presents the results of the t-tests used to check if the differences are significant, as our data is normally distributed (tested with the adjusted K-S test). The scores represent the percentages of correct answers as described in the measurement section. As seen, hypotheses 1 to 4 are supported.

Table 1. Comparison of knowledge structure results between both groups

Construct	*2D world*	*3D VW*	*Difference (%)*	*Hypotheses*
No splits	.49	.56	14.3	H1: Supported; T(143) = -2.147, p < .05 (FDRC: .028)
XOR-splits	.51	.58	13.7	H2: Supported; T(143) = -1.758, p < .05 (FDRC: .052)
AND-splits	.37	.41	10.8	H3: Supported; T(143) = -1.302, p < .10 (FDRC: .098)
OR-splits	.33	.40	21.2	H4: Supported; T(143) = -2.495, p < .01 (FDRC: .018)

Addressing hypothesis 5, comparing the scores regarding OR-splits with the other connections show a non-significant result (T(292.9) = .762, p = .78). This result is supported by the confidence intervals (retrieved by applying a bootstrapping procedure) overlapping for each type of splits (XOR-splits: -0.141 – 0.007; AND-splits: -0.99 – 0.020; OR-splits: -0.130 - -0.015; No splits: -0.129 - -.007). Nevertheless, there is some descriptive tendency as the difference between the virtual and the 2D world is the highest one compared to the others and the absolute knowledge structure results show that the lowest values can be found with OR-splits.

Participants perceived both worlds as being statistically similar in terms of difficulty (T(143) = -1.945, ns) and also the interest of participants in both groups was similar (T(143) = -1.392, ns). Age (T(143) = .527, ns), gender (Chi2(1) = 3.886), prior modeling experience (T(143) = .013, ns), job experience (T(143) = .467, ns), CRT (Chi2(3) = 6.238, ns) and GLT (T(143) = .471, ns) do not differ between both groups.

For a further robustness check, participants received the respective other world after answering the questions. Their rating (1-7) of both worlds in comparison reveals that participants of the 2D-group rate the 3D-world (5.37) significantly higher (T(124) = 5.906, p < .001) than the 2D-world (3.64). There is however no difference in this regard with participants of the 3D-group (T(137.98) = .685, ns) with only a slight tendency towards the 3D-world (3D-world: 4.25; 2D-world: 4.04).

5 Related Work

Previously, the use of VWs for BPM has been pioneered by the authors to investigate topics such as remote collaborative modelling [39]. More pertinent to this research has been the positive results from using VWs [8] and immersive virtual reality [19] to elicit process model information from experts. Both these applications have shown successful results in terms of assisting users to collaborate and model more effectively [39] and to provide more accurate and plentiful information.

Other applications of method of loci in VWs and virtual reality include general list memory problems [40-44] and language acquisition [45]. In this work, we take advantage of the representational fidelity and utilize spatial affordances of VWs to create an explicit representation of a process model that supports the method of loci approach. We note that our work is the first to utilise this approach within the field of process training and education.

Amongst industry process simulation systems [46], the closest to our work is OnMap (www.onmap.com), a 2.5D world system for visualising business processes. However, in comparison to OnMap, we have formalised process representations more clearly from a theoretical pattern basis, improving the mapping between the defined process perspectives. We also utilise a first person view of the process being executed, which utilises the method of loci effectively, as the user is transported through the scene, providing episodic traversal of the routine to be remembered [10].

6 Discussion, Implications, and Limitations

Our study sets out to analyze the impact of a 3D VW visualization of processes on understanding the knowledge structure of processes focusing on gateways. The results show a significant positive effect of using a 3D VW visualization compared to a 2D process visualization. These results hold for the representation in general and regarding our hypotheses for the three typical gateways specifically. However, contrary to our underlying hypothesis, we cannot observe a stronger effect for OR-splits than for the other gateways constructs.

Hence, while a 3D VW is assumed to allow for a better representation of several alternatives, the results can be interpreted that either a different overview is required or that OR-splits are not that complicated to understand. We conduct a post-hoc test, comparing the four types of splits with each other within the 2D and 3D representations separately. The results show that the knowledge structures of the process for both OR-splits and AND-splits are significantly lower than for XOR-splits and no splits ($F(3, 280) = 14.928$, $p < .001$, Games-Howell: OR/XOR, $p < .001$, OR/AND, ns, OR/NO, $p < .001$; $F(3, 292) = 17.160$, $p < .001$, Games-Howell: OR/XOR, $p < .001$, OR/AND, ns, OR/NO, $p < .001$). These results indicate that OR-splits are more difficult, but similar to AND-splits. In order to understand these splits better, different learning mechanisms than addressed with our 3D VW visualization have to be triggered. An approach could be to repeat such sequences more than once or provide additional verbal explanations. Another design consideration comes into play when there are more than two branches within XOR/OR/AND split and joins. More than two camera views would be needed to represent such a structure, which would increase the cognitive load of the reader. A different 3D VW visualization may be developed to represent those structures in a cognitively-efficient way.

Our study has implications for BPM research. First, our results show that 3D VWs can be applied successfully to provide a new way of representing and transferring process knowledge, helping especially to understand complex gateways. While the current literature focuses mostly on notational and personal factors, the need to introduce innovative visualization approaches has been defined [6]. Considering that VWs provide a replication of a real-life setting, typically, a specific instance of a process without considering alternative flows is depicted in a VW. Our results indicate that VWs can be set up to explicate the meaning of gateways in process models, therefore, reflecting the knowledge on the process domain together with notational elements. Thus, while the knowledge captured in a process model is transferred to the learner, the learning process is also improved in VW with respect to gateways. Second, our results contribute to the relevancy of the method of loci in the domain of learning processes. As such, we extend prior work from other domains such as [16] by showing that it is important to design training systems with a 3D VW to ensure a better understanding of processes.

Our research has also practical implications. Although process models are heavily used to communicate process knowledge to diverse process participants [47], specifically for participants from non-technical backgrounds, it is difficult to map real-world concepts to process model elements [7]. To ensure that process knowledge is acquired properly, organizations can provide process trainings to its stakeholders [48]. Various solutions are used for this purpose, such as in-class training, role-playing, or on-the-job training [2], which are costly and may not be always feasible. Specifically as the number of stakeholders to be trained increase and they become geographically diverse, scalability and logistical issues arise. VWs can provide a comprehensive training solution for organizations to overcome such problems. Their current process models can be used as input to easily set up the VW environment [33]. Such a system has to be set up once, but can be distributed among a large number of employees.

Limitations of our study are as follows. First, we pick a sample process in a specific context. While the process has been chosen carefully to be representative, there might be differences if other processes with different structures are used. This refers to the complexity in terms of having more or fewer number of connections and gateways, as well as the context. Second, the participants of our experiment are students which have a different behavior from employees having profound experience in understanding processes. Experiments in behavioral operations management have shown that there are no significant differences in decision-making behavior between managers and students [49] and students are frequently used as proxies to novice professionals in BPM context [29]. Nevertheless, this should be taken into account when interpreting the current results. Third, although the experiment results ensure a high internal validity, when using a VW environment in a company, there might be an influence of the perceived and experienced real environment.

7 Conclusion

Our study provides evidence that a 3D VW environment contributes to understanding processes significantly better with different effects for gateways. While the result is encouraging to strive for 3D VW visualization of processes, there are still open questions that require further research.

Future work should analyze whether the effect observed in our study changes with the complexity of the process model used. The complexity can be varied with regard to the number of connections as well as the proportion of the gateways. Such an analysis can potentially result in defining thresholds regarding the effect strength in terms of process model complexity. When there are more than two branches within gateways, there may be better ways of visualizing the activities in multiple branches rather than using camera views side-by-side. Alternative 3D VW visualizations for complex parts of the process model should be developed based on the complexity.

Further work should also concentrate on comparing the 3D VW and the 2D depiction using a regular BPMN notation. While this can be considered as an extra effect, thus, has been excluded in targeting the basic effect as done in this paper, additional insights can be gained regarding the effect of using a specific notation. Such an analysis would also require distinguishing between experts being used to BPMN and novices to determine the effect of the notation and the graphical representation.

Finally, it would be promising to analyze the effect of using a 3D virtual representation on work behavior in a real world environment. Such an analysis not only refers to the knowledge regarding processes, but also regarding the consequences in terms of process efficiency and process-oriented behavior. The effects on work behavior should be observed over a time period of several months to determine whether sustainable effects going beyond using traditional process models can be achieved.

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