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Process training for industrial organisations using 3D environments: An empirical analysis

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ABSTRACT

Industrial organisations spend considerable resources on training employees with respect to the organisations' business processes. These resources include business process models, diagrams depicting vital activities, workflows, roles, systems, and data within these processes. However, these models are difficult to comprehend, partly because they possess minimal connection to real-world concepts. Alternately, 3D environments allow greater learning opportunities for process-related knowledge. To this end, we designed a non-interactive 3D environment for process training purposes that allows learners to apply the method of loci, which has been shown to improve learning by helping associate visuospatial elements with learning material. The prototype environment, which was developed using simple visualisations, can be adapted across industrial organisations and domains. In order to test the effectiveness of the 3D environments in comparison with 2D environments, we conducted a between-subjects experiment with two conditions. The results show that 3D environments result in more accurate and faster recall of process knowledge, suggesting that such an environment can provide a better affective learning experience. These findings have important implications for how organisations can train their employees with the aim of improving the acquisition of process knowledge.

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1. Introduction

It is crucial for employees to be aware of the processes they are part of in order to ensure overall process efficiency (Škrinjar and Trkman, 2013). Employees who are aware of the overall processes within which their activities are embedded – that is, those with a process orientation – are better at orchestrating their activities with colleagues, which enhances process flow and innovations within the organisation (Leyer et al., 2017). It is vital for industrial organisations to ensure that operations continue via the appropriate machinery and that issues are resolved quickly; thus, shop-floor and supporting employees need to have an overarching comprehension of these larger processes and not just knowledge of their own responsibilities. These overviews are typically provided through business process models aimed at transferring process knowledge to process participants (Wand and Weber, 2002).

Process models, however, do not adequately support the formation of knowledge structures within processes due to the abstract nature of these structures; readers of process models, especially if they are not process modellers themselves, will not be able to easily map process model elements to real-world concepts or create experiential memories of the processes (Figl et al., 2013). As a result, in practice, process participants often lack adequate knowledge of the processes within which they work (Leyer et al., 2015). Accurate knowledge structures of processes are vital for making improvements and innovations that consider the whole process and facilitate shared understanding (Tang et al., 2013). Industrial organisations spend significant resources documenting processes, organising training sessions, and providing on-the-job experiences to help employees acquire and improve their process knowledge (Dumas et al., 2018; Indulska et al., 2009).

Three-dimensional (3D) virtual environments provide a number of learning affordances to facilitate the transfer of process knowledge that can form knowledge structures within a situated context (Dalgarno and Lee, 2010). Virtual environments are an interactive

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technology wherein the computer synthesises a virtual-interactive reality as a synchronous, persistent network of people, represented as avatars, facilitated by networked computers (Bell, 2008). Prior studies in industrial contexts have shown that 3D environments can be beneficial on the shop floor, as well as in supporting activities (Fillatreau et al., 2013; Geng et al., 2020; Guo et al., 2018; Kopácsi et al., 2013; Pérez et al., 2019). However, general training tools and knowledge of motivational aspects are currently lacking (Borsci et al., 2015). Therefore, 3D environments present a potentially advantageous setting for training individuals on business processes within an industrial context.

The method of loci is a knowledge-acquisition method that is widely used to improve learning by associating visuospatial elements with learning material (Dresler et al., 2017). It requires the learner to place each item to be learned in their "memory palace" and to "visit" items in their assigned locations (Yates, 1966). Since the method of loci enables individuals to successfully recall visuospatial routines, its use in 3D environments is promising for process training and could help overcome the shortcomings of traditional 2D process environments (Figl, 2018). The method has been shown to improve learning in various contexts, such as language, history, economics, and physiology (Huttner et al., 2019). However, building a mental representation, or a memory palace, for each learning task represents a cognitive challenge for learners (Lim et al., 2020); 3D environments can ease this cognitive load by providing a default template (Reggente et al., 2020). Additional challenges arise regarding the establishment of a memory palace that the learner can easily relate to (Shaughnessy and White, 2012) and instructing the learner about building the memory palace and locating the items that need to be learned (Huttner et al., 2019). Such challenges are pertinent to industrial 3D solutions, which require an immersive and easy-to-use experience, as well as a cognitive connection with the context (Fillatreau et al., 2013).

We focus on creating a simple but general visualisation approach in which learners can use the method of loci to improve process learning. The cognitive load of building a memory palace can be alleviated by depicting familiar industrial locations and visuals of the process. This can also help the learner to connect new knowledge with existing knowledge (Reggente et al., 2020). The use of a familiar environment and process routines provide an organic visit strategy to the learner, rendering instructions unnecessary. Fig. 1 schematises how the method of loci can be used in 3D environments to design a better learning environment compared to 2D process environments. Furthermore, representing process model elements in a 3D environment can allow for abstract symbols to be embodied as real-life concepts within the environment in which they are used (Dawley and Dede, 2014). Hence, experiential memories, which are stored in the long-term memory, can be created to enhance the recall of process details (Sauzéon et al., 2012).

To understand the use of 3D environments for improved process learning in an industrial context, we pose the following research question:

> How does the process model visualisation design of a 3D environment setting improve acquisition of the knowledge structure of processes compared to training in a 2D environment?

To answer this question, we developed a 3D environment for an issue-resolution process within production management with the aim of helping employees acquire a better understanding of process knowledge structures. Further, we performed a between-subjects experiment comparing a non-interactive 3D environment setting to a stepwise-presented 2D environment in order to measure the recall accuracy, recall speed, and emotional responses (pleasure, arousal, dominance). We presented the process of the experiment

step by step, allowing the participants to easily understand the flow of activities involved in the process.

This study contributes to the limited literature on the use of 3D environments in job training, especially with regard to processes in organisations (Borsci et al., 2015; Bosch-Sijtsema and Haapamäki, 2014). Most research on 3D environments has focused on simulating operational and physical tasks in 3D environments that have been developed for single use on a specific task (Borsci et al., 2015; Stefan, 2016). This paper is among the first to train people in process concepts within non-interactive 3D environments (Figl, 2018) using a generic and configurable visualisation approach (Geng et al., 2020) that can be applied to information-based tasks in production management. The prototype employs simple visualisations that would be adequate for office tasks but can also be adapted to physically complex shop-floor processes through the use of elaborate 3D visuals.
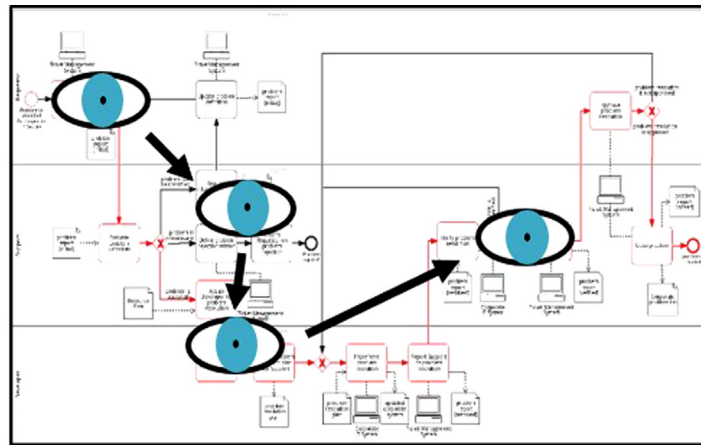
2. Background

2.1. Conceptual background: process learning

A business process can be described as a number of inter-related activities aimed at establishing a certain goal (Davenport and Short, 1990). Information is received from customers and then processed through various activities. Typically, there is a logic behind the way in which activities are connected with each other and how information flows among these activities. The connections can range from a linear process flow to a complex flow based on conditions and decisions (Collier and Meyer, 1998), and often constitute the routines of work within the process.
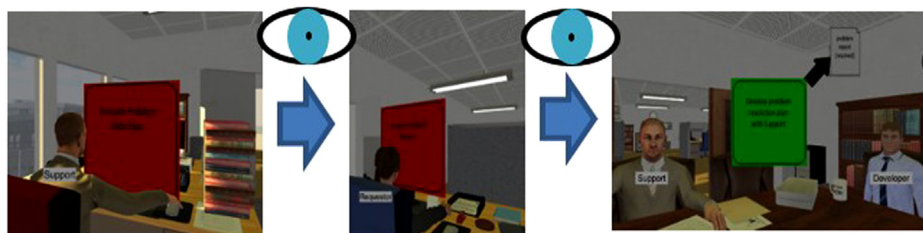
To achieve business process efficiency, employees are not only required to maximise their personal efficiency in an activity but also to coordinate their activities with those of the other employees involved (Babić-Hodović et al., 2012). For example, in order to reduce cycle time, it is usually insufficient for individual employees to enhance their own activities in an isolated way. Instead, employees need to refine the information provided to them for others who will carry out subsequent activities. However, in order to expend joint effort to improve efficiency, employees need to know how the various activities are connected and who will be performing these activities (Chen et al., 2009). This implies that employees need to develop a knowledge structure of process routines. Process models can help visualise these routines through connected symbols, such as by using rectangles to represent activities. However, since these symbols are abstractions of real-life concepts (Figl et al., 2013), it is difficult to develop the knowledge structures of routines from process models (Leyer and Strohhecker, 2017). Conversely, using process models for training according to the method of loci represents a promising approach since the process routines of the models provide the necessary input for such training. Employing the method of loci requires the process elements to be represented as visuals within a real-life environment. In this way, learners can visually traverse process routines from a process flow perspective, as suggested by the method of loci, and develop experiential memories (Dresler et al., 2017).

2.2. Theory and related work: Cognition and learning in 3D environments

Knowledge acquisition in learning is supported and enacted by human memory systems (Baddeley et al., 2015). Humans acquire knowledge and contextual information about the task being performed through mental and physical actions. Psychological models of human cognition involve the relationship between the human body and its surroundings. Thus, we develop a situated knowledge

2D diagrams lack simulated movement to spatial locations; the diagram is traversed solely using eye movements, and there is no egocentric visual flow.

3D VE enhances item recall by simulating physical experience at each location, producing egocentric visual flow as in the case of human body movements.

Fig. 1. High-level conceptual diagram demonstrating the integration of 3D environments and the method of loci to form a better learning environment compared to 2D process environments.

of things through actions performed from an ego perspective that is embodied in reality, referencing the world through embodied senses (Turner, 2016). This concept is supported by several experiments that indicate the effects of embodied contextual information on memory; for example, Dijkstra et al. (2007) found that experiential details from a dental appointment are remembered with greater ease when a person is made to recline in a chair during recall, owing to the similarity of posture with that during the dental appointment.

The idea of situated knowledge has led to learning approaches that draw upon situated learning theory to be applied in educational settings (Brown et al., 1989); this posits that people learn best when the knowledge is learned in the context in which it will be used (situated). Situated learning facilitates the recall of specific activities by priming the knowledge with the appropriate context. Previous studies have highlighted 3D environments' potential to support situated learning through high-fidelity immersive visuals that also provide the context (Dawley and Dede, 2014).

The simulations within 3D environments strongly affect the memory processes of individuals using them (Bailenson et al., 2008) owing to the ability of 3D environments to synthesise a simulation of reality as a perceptually immersive and interactive experience (Pérez et al., 2019). Moreover, the use of immersive embodied movement within 3D environments has been shown to be superior for training purposes (Bailenson et al., 2008). These results indicate that such environments have a strong impact on memory recall, which may be greatly improved as a result of the rich stimuli pro-

vided. Psychological theory, especially that of extended cognition, posits that our knowledge is embedded within our bodies and its interaction with surrounding environments (Clark, 2010); when we access and use available artefacts in the world, their affordances or functional capabilities prime our brains by embedding memories of their use.

Knowledge can be stored in a person's memory for retrieval either as an *explicit* memory (a visually recallable memory in time) or as an *implicit* skill recall (bodily response to the tasks at hand without recourse to visual memory) (Turner, 2016). To contextualise our research, we focus on the recall of *explicit* memory, particularly with regard to *semantic* items that relate to a surrounding context to form an *episodic* memory context to aid recall (Taylor and Evans, 1984). We note that 3D environments need to support episodic memory recall for process training since, here, the main blocks of processes that need to be learned are activities (van Der Aalst et al., 2003), which are semantic items related to a process context. The potential of 3D environments to create explicit memories of processes situated in real-life contexts motivates us to further investigate the use of 3D environments in process training.

2.3. Hypothesis development: Effects of 3D environments

The method of loci approach requires us to lay down the memories of visuospatial routines, which will then be used later to remember information by visualising the same routine in the imagined environment (Yates, 1966). Several knowledge acquisition and

training approaches build on this approach (Dresler et al., 2017), and it has been proven as an effective method for the mnemonic memorisation of information in behavioural studies (Worthen and Hunt, 2011), macroeconomics (Shaughnessy and White, 2012), chemistry, and history (Lim et al., 2020). During the method's application, the learner imagines a place, such as their own house, and devises ordered actions in various locations – such as waking up in bed and having breakfast in the kitchen – each of which they then relate to an item on the learning list, such as a list of groceries (Massen et al., 2009). The learner then traverses the locations in their mind while relating them to the learning item. Recent studies have shown the effectiveness of the method of loci in modifying physiological network structures in the brain to enhance recall (Dresler et al., 2017). Similar training effects may be enacted by viewing 3D environments on computers. For example, when using avatars as surrogate bodies in 3D environments, from visual input alone the human brain undergoes similar changes in the hippocampus as it does when moving in a physical reality, even though the body is not in fact moving (Gould et al., 2007).

Applications of the method of loci in 3D environments, including virtual reality, cover general list memory problems (Huttner et al., 2018a; Huttner and Robbert, 2018; Huttner and Robra-Bissantz, 2017; Krokos et al., 2018) and language learning (Ralby et al., 2017). 3D environments can overcome the challenge of relying on the learner's imagination by creating a cognitive burden (Huttner and Robra-Bissantz, 2017) and visuals related to the concepts, which improve learning (Huttner et al., 2018b). Using the same visuals in the process setting would provide a familiar setting for the learner to prime the new information with their existing knowledge (Massen et al., 2009). 3D environments have been shown to be effective even without instructions when the method of loci is applied (Huttner et al., 2019). Process routines prescribe a visit strategy while implementing the method of loci that naturally fits the learning task. Therefore, traversing the process routines in a 3D environment in which the process takes place may help learners improve their acquisition of process knowledge, resulting in their enhanced recall of processes. We expect that learners in a 3D environment will remember more activity connections from the process routines, as described in Section 2.1, and will more rapidly remember the information compared to those who learn using a 2D environment. Time is an important factor, as the faster one can recall a model, the less time it takes to be able to execute a process properly (Borsci et al., 2015).

Thus, we posit the following hypotheses on the use of 3D environments for process training:

H1a. The use of 3D environments will lead to higher recall accuracy regarding knowledge acquisition of processes, compared to using a 2D environment.

H1b. The use of 3D environments will lead to higher recall speed regarding knowledge acquisition of processes, compared to using a 2D environment.

Previous studies have highlighted that the use of 3D environments in learning tasks can result in increased intrinsic motivation and engagement (Choi and Baek, 2011). 3D representation of process models can help to depict process activities vividly (Figl, 2018), and may motivate learners to train on processes more often (Borsci et al., 2015; Sailer et al., 2013). Extant research has also shown that emotional responses are enhanced by 3D environments owing to the positive relationship between presence (i.e., sense of "being there" in a 3D environment) and emotions (Aymerich-Franch, 2010). Positive emotions have a significant impact on learning outcomes within multimedia learning environments (Huang et al., 2013), leading to increased attention, motivation, and learning interest (Kim and Pekrun, 2014). Noteborn et al. (2012) studied the

relationship between emotions and learning performance in a virtual world setting and showed a significant relationship between enjoyment and exam performance (pleasure). Huang et al. (2013) examined learner experiences in the context of tourism education in a 3D environment setting and found a significant relationship between learners' sense of autonomy and positive emotions (not being dominated). Furthermore, participants' arousal (the extent to which they felt activated) has been observed to be positively affected in 3D environment settings (Estupiñán et al., 2014). Thus, the high levels of interactivity and fidelity of 3D environments lead to emotional responses among learners, thus improving their learning experiences (Mikropoulos and Strouboulis, 2004). We summarise these three dimensions in H2a to H2c, as follows:

H2a. The use of 3D environments will have a positive impact on pleasure during knowledge acquisition of processes, compared to using a 2D environment.

H2b. The use of 3D environments will have a positive impact on arousal during knowledge acquisition of processes, compared to using a 2D environment.

H2c. The use of 3D environments will have a positive impact on feeling dominant during knowledge acquisition of processes, compared to using a 2D environment.

In the following section, we describe how we designed our environment to exploit the affordances of 3D environments, the method of loci–based memory effects, and the emotional impact of process training. We also detail our exploratory experiments performed to validate the new training approach.

3. Design description of the 3D environment

We developed a 3D environment for process training in an industrial context based on the method of loci. In line with our theoretical background, we set out to design an environment that applies situated learning and the method of loci for process routines. By using this environment, we aimed to enhance individuals' process recall in terms of their recall accuracy (H1a) and speed (H1b), while facilitating in them a higher emotional response during knowledge acquisition (H2a–c). Fig. 2 comprises screenshots from the environment. (The environment is detailed in Appendix 1-A.) By following the design factors, the training environment can be configured rapidly for different information-based processes in industrial environments based on a process model.

3.1. Design factors to apply situated learning

3.1.1. Spatial environment of the process

The training system provides a 3D environment that represents real-life elements relevant to the context of the current process. We selected an exemplary (but generic) process that takes place in an office environment and supports the shop floor of production (Lindsay et al., 2003). The environment is designed such that separate office spaces represent different roles to perform individual and collaborative activities such as meetings. Visual cues are used to distinguish spaces from each other. For example, while an avatar performing the support role is placed at a distinctive desk next to the window with a city view, the developer role is placed in a cubicle (a spatially different location in the office) with different items on the table. In this way, we create a situated context of the real-world environment where the process takes place (Dalgarno and Lee, 2010).

3.1.2. Human-centric view

Each role performing an activity in the process is represented by a unique avatar to enable learners to visually prime different roles.

Fig. 2. Two screenshots from the environment, showing the role *Support* performing the activity of assigning a developer for problem resolution (left) and the role *Developer* performing root-cause analysis (right).

Fig. 3. Prepare pattern example images for each step showing an output document created using an information system.

Fig. 4. Evaluate pattern example images for different activity statuses, ending with a choice dialog ample image for the last step.

3.1.3. Process element visuals

To represent process elements related to activities other than the roles – namely inputs, outputs, and IT systems – we use icons labelled with the names of the related elements. We follow an abstract representation style for these elements borrowed from the symbols of process modelling notations, specifically BPMN (Chinosi and Trombetta, 2012), since they are not distinguishable through their physical form in the office environment. For activities that involve other parties, such as when an output is handed over to another role, the role itself is represented as a small avatar. The activity name is abstracted as a rounded rectangle, which is a symbol frequently used in process modelling notations.

3.1.4. Location-based activities

We place the activities in discrete locations based on the type of activity. For individual activities, separate office spaces are used for each role while meeting rooms are used for collaborative activities.

3.1.5. Activity patterns

To support users in distinguishing actions based on the visuals in the 3D environment, we classify each activity based on the inherent nature of the action specified on its label and its relations with other process elements. We follow the pattern approach com-

mon in the business process field to categorise the type of action, and design the visuals accordingly (Leopold et al., 2012). On a high level, we classify activities as individual and collaboration activities. Individual activities are further categorised into personal and decision types, whereas collaboration activities can be of group, data transfer, or delegation type. 3D environment office locations and process element visualisations are set up depending on the pattern to which an activity belongs. Fig. 3 shows the sequence of visualisations for an activity conforming to the prepared pattern. Fig. 4 presents all the activity status changes for an activity of the evaluated type, which is finalised with a choice dialog. Fig. 5 depicts an activity following a mutual work pattern using two roles in a meeting room.

The use of unique avatars for each role, separate visuals for process elements, and visualisation of activities based on the type of action enable learners to prime structures of the process routine in the situated context of the process to create experiential memories.

3.2. Design factors to apply the method of loci

3.2.1. Traversing activities in a process routine

In the situated context of the process environment, the user traverses each activity in the order indicated by the process routine

Fig. 5. Mutual work pattern ex.

by a camera following a third-person view. The 3D environment camera moves from one location to the other, where the associated role(s) are placed and the activity is performed, applying the method of loci by traversing visuospatial process routines.

3.2.2. Change of activity status

The feeling of progression through activities performed in order also includes the change in the status of activities; i.e., initiated, performing, finished (Weske, 2007). Accordingly, in our environment, when the camera moves to a new activity, the activity symbol is shown in red, which indicates that the activity is initiated and thus is ready to be executed. In the next step, the activity colour changes to amber, indicating that the activity is being performed. The inputs and the system(s) being used, if any, appear during this step. For activities that include making a decision, a decision table is also represented. In the last step, the colour turns to green and the outputs are shown to signal the completion of the activity. The colour choice thus follows a traffic light metaphor (Smyth et al., 1995). With this design, we provide a feeling of progression for an activity execution and explicate the use of different process elements such as inputs and outputs. In this way, the method of loci is applied not only to the activities but also to changes in the status of activities during a process routine.

3.2.3. Interaction basis

Based on the segmentation principle, in order to manage the cognitive load related to the training material we provide a user-controlled flow from one activity to another for the status changes of activities (Moreno, 2007). For this, users only need to perform a simple interaction through button presses. In this way, we keep the interaction minimal to lower the cognitive load associated with selecting and applying necessary interactions (Paas et al., 2007), allowing the learner to focus only on traversing the process routine.

The described design allows us to exploit the method of loci and situated learning in numerous ways. Overall, the design is shaped around the traversing of activities in a process routine in distinguishably different locations with the aim of creating situated visuospatial memories. A human resource–centric view provides not only location-based but also person-based cues for learning. A generalised visualisation is achieved with simple abstract representations of process elements in the environment and the design of the space of execution for each activity based on activity patterns. The placement of relevant elements in the 3D environment enables an immersive experience through visual priming, stimulating participants' engagement with the environment for improved emotional response. Therefore, this design enables us to exploit

the method of loci in a 3D environment to improve process learning and thus create better knowledge structures with higher emotional impact during learning.

4. Methods

4.1. Experiment design and materials

For this study, we selected issue resolution as an example process to represent a typical process within production management, which involves solving upcoming problems and ensuring continuation of operations. The complete process model of the selected process in BPMN notation is shown in Fig. 6. This process model depicts the activities performed by the roles *Requestor*, *Support*, and *Developer* in an organisation when a problem is identified in the corporate IT system. The selected process routine, highlighted in red in the figure, consists of 11 activities, two IT systems supporting machines on the shop floor, four inputs, and eight outputs.

The experiment followed a between-groups design (Field and Hole, 2002). The treatment consisted of using various environments of the process prior to asking participants questions in order to evaluate their knowledge structure and experienced emotions about the process. Both groups could click through the process step by step, with the control group moving through a 2D environment (the protocol is described in Appendix 1-B) and the treatment group through a 3D environment[1].

In designing the learning environments for the 3D environment and control groups, we favoured internal validity, to achieve comparable results, at the expense of ecological validity. More specifically, in the control group the stepwise presentation of the same process in a 2D environment provides a comparable approach to the visualisations in 3D environments, where the animation and status change to equalise the possible positive effects of animation. Additionally, our 3D environment setting deviates from industrial software tools owing to its lack of interactivity; however, this helps to lower the cognitive load involved in using it (Kalyuga and Liu, 2015). Thus, the environment as it is currently designed may not be directly usable in an organisation but it provides a controlled lab experiment through which to observe the effects of 3D environments on process knowledge acquisition.

4.2. Measures

Participants' recall performance was measured according to their understanding of the given process – i.e., the knowledge structure – using the procedure described by Leyer and Strohhecker (2017). Recall testing is a common method in learning studies to measure the effect of a learning environment on domain memory (Boucheix and Schneider, 2009; Mendling et al., 2012), and is particularly suitable for our experiment to compare the acquired knowledge structure of the participants. Participants were asked 25 questions (see Appendix 1-E, Post-Questionnaire) on the relationship between the two activities. For each pair of activities, participants were asked to determine whether activity A was directly followed by activity B; if this was not the case; or if they did not know. Since the process in the experiment contained 12 correct relationships, 13 incorrect ones were added in order to avoid random guessing. Hence, 48 % of the statements were correct, 20 % were completely wrong, 17.4 % indirectly followed with one additional activity between A and B in the real process, and 14.6 % indirectly followed with two activities between A and B. We

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[1] An example process execution video can be viewed here: http://www.expertjudgment.com/PMTraining/3DVe-ProcessTraining-ExampleRun.mp4, and the application can be found in Appendix 1-A.
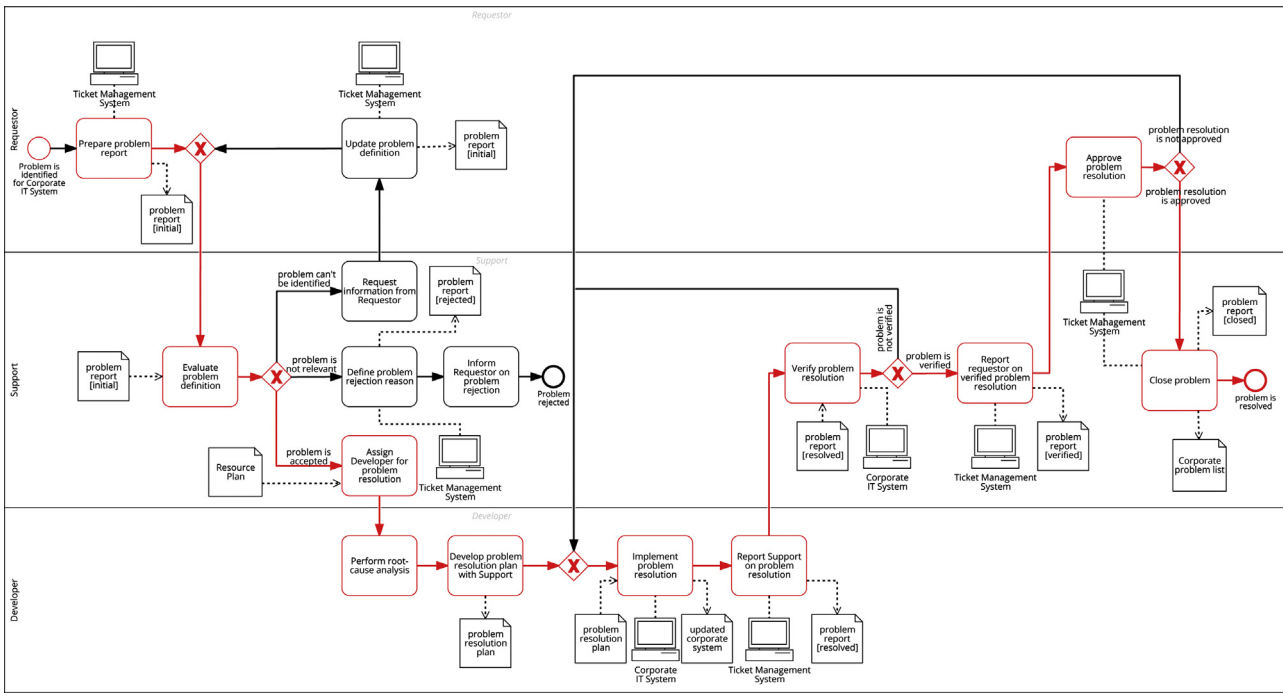
Fig. 6. Underlying process model used to design the experiment.

counted the number of correct answers to identify the 12 correct relationships and calculated a percentage for each participant. We measured the recall accuracy to test H1a using two criteria (Leyer and Strohhecker, 2017): (1) identifying correct connections in the process and (2) distinguishing correct connections in the process from false ones.

To test H1b, pertaining to recall speed, we measured the amount of time that participants needed to answer the 25 questions regarding knowledge structure by having the participants document the time before starting and after completing the questionnaire.

To test H2, pertaining to the difference in the emotional impact experienced by participants while using 3D environment and a 2D environment, we measured the perceived emotions associated with the viewing of the process. For this purpose, we used the independent emotion dimensions of pleasure, arousal, and dominance, which may be affected by the use of a system (Hibbeln et al., 2017). We used the self-assessment manikin technique (Bradley and Lang, 1994) to measure the perceived emotions of the participants in these dimensions. Participants could select the manikin directly or a point between two manikins leading to a scale from 1 to 9.

We employed control measures to check whether the two groups differed in terms of characteristics that may have affected the formation of knowledge structures. First, we controlled for personal characteristics that are considered to influence how participants process learning material, including process modelling and job experience (Figl et al., 2013), analytical–intuitive thinking, and global–local processing styles (Bradley and Lang, 1994; Weinhardt et al., 2015). Second, we checked for measures regarding how participants experienced the learning process in the experiment. To this end, we asked about participants' interest in or motivation towards understanding the presented process (Baars et al., 2017); a higher interest in the process led to a more positive effect on memory independent of the type of environment. This was followed by the time required to view the presented process (Boucheix and Schneider, 2009), and the perceived cognitive load during learning (Figl et al., 2013). To measure these variables, we asked participants for self-reported values about their experience, interest in learning the process, perceived cognitive load, and time

taken to view the process. We employed tests from the literature to measure analytical–intuitive thinking and global–local processing styles (Weinhardt et al., 2015), as well as cognitive load (Chen et al., 2011) (all questions can be found in Appendix 1-E).

4.3. Selection of the participants and procedure

Participants were graduate students; this group has been demonstrated to exhibit similar behavioural outcomes to employees in the context of researching process behaviour, since basic behavioural effects are not strongly affected by professional experiences (Croson and Donohue, 2006; Narayanan and Moritz, 2015). Participants were from a business background and were randomly assigned to the treatment and control groups, with 30 participants in each group. In addition, a post-hoc analysis was conducted with 10 experience participants in each group from industry.

Participants performed the experiment on their own, without making any contact with others and without any time pressure. In the first part of the experiment, each participant was randomly provided with either the 2D environment of the process (control group) or the 3D version of the process (treatment group). During the training, participants could not make choices but could click through the process. Participants were instructed to observe the process carefully with the aim of reporting on the process structure afterwards. They were also told that they would be required to provide a measurement of accuracy and time. After viewing the process, participants immediately received a post-questionnaire containing the described measures (the complete procedure followed during the experiment can be seen in Appendix 1-B to 1-E).

5. Results and discussion

5.1. Descriptives

The average age of the participants was 23.60 years (SD = 2.96), and 75.0 % were male. The participants had initial practical experience; average prior experience with modelling processes was 2.5 months (SD = 5.16) and average work experience in general (inde-

Table 1
Descriptives for the variables related to the hypotheses.

	Group 1 (2D environment) (n = 30)		Group 2 (3D environment) (n = 30)		Total (n = 60)		Normality
	Mean	SD	Mean	SD	Mean	SD	
Identification – Criterion 1 (H1a) (max = 1.0)	0.36	0.21	0.49	0.16	0.42	0.19	Normal (K–S = .137, p > .001)
Differentiation – Criterion 2 (H1a) (max = 1.0)	0.36	0.19	0.45	0.13	0.41	0.16	Normal (K–S = .105, p > .05)
Time – Criterion 3 (H1b) (minutes)	6.07	2.30	4.83	1.53	5.45	2.04	Not normal (K–S = .237, p < .001)
Pleasure – Emotion 1 (H2a) (scale of 1–9)	5.83	1.21	6.83	1.26	6.32	1.32	Not normal (K–S = .239, p < .001)
Arousal – Emotion 2 (H2b) (scale of 1–9)	4.40	1.43	6.00	1.46	5.19	1.65	Not normal (K–S = .196, p < .001)
Dominance – Emotion 3 (H2c) (scale of 1–9)	4.53	1.81	3.10	1.11	3.83	1.66	Not normal (K–S = .234, p < .001)

Notes: SD = Standard Deviation, Normality = result of K–S normality test.

pendent from issue resolution) was 19.3 months (SD = 28.31). The average interest of participants in understanding the presented process was 5.12 (scale 1–9). This shows that most participants took the task seriously. Table 1 provides an overview of the descriptives for the main variables as described in the measurement section.

5.2. Validation results

The validation criteria as described in the measurement section, regarding the control and treatment groups, were tested using the *t*-test for normally distributed data and the Mann–Whitney *U* test for non-normal data. Since we had four dependent variables to be tested in four independent tests, we applied a false discovery rate correction (FDRC). The values were reported after the independent test results.

To test H1a, we used two criteria. Criterion 1 measured the percentage of connections of the process correctly identified by a participant. The results of criterion 1, for which we assume that a virtual representation of the process leads to a higher score, are significant (T(53.85)=-2.631, p = .005, Cohen's d: .717, FDRC: .008). The participants of the treatment group showed a mean value of .49, compared to .36 in the control group; thus, the former is a better result by 36.1 %. Criterion 2 reflected the percentage of correctly identified correct connections from the false ones. The values for criterion 2, for which we assume that a 3D environment leads to higher values, is again significant (T(50.73)=-2.193, p = .016, Cohen's d: .616, FDRC: .016). The results of the mean values indicate a higher value in the treatment group (.45 compared to .36), which is 25.0 % better. Thus, H1a can be confirmed with a medium effect size (Fritz et al., 2012).

H1b postulates that the use of 3D environments for the knowledge acquisition of processes will lead to a higher recall speed compared to experiencing a 2D environment. In this regard, criterion 3 measured the time taken by participants to answer process-related questions. The values for criterion 3, for which we assume that the participants in the treatment group take less time to report their knowledge structure of the process, is significant (U(299.5)=-2.276, p = .012, R^2 = .09, FDRC: .014). The participants

in the treatment group took 4.8 min on average, while participants in the control group needed 6.1 min, taking 27.1 % more time. Thus, H1b can be confirmed as having a medium effect size.

The results for H1a and H1b are in line with the literature applying the method of loci and using 3D environments in other domains as discussed in Section 2 (Huttner et al., 2018a; Huttner and Robbert, 2018; Huttner and Robra-Bissantz, 2017; Krokos et al., 2018). Overall, our study shows the applicability and benefits of these concepts for process training of employees within an industry, which is an essential and challenging activity in an organisational context (Dumas et al., 2018; Indulska et al., 2009).

H2 states that the use of 3D environments for the knowledge acquisition of processes will entail more emotional impact compared to experiencing a 2D environment. We observed significant differences in emotions measured in 3D through H2a to H2c. Participants in the 3D environment group had a significantly higher rating for positivity, indicating that they felt more pleasure (Bradley and Lang, 1994) while learning the process compared to those who learned with the process model presentation (T(57)=-3.103, p < .001, Cohen's d: 0.822, FDRC: .002). The 3D environment also led to participants feeling more arousal, as represented by the higher ratings on being active (Bradley and Lang, 1994) (T(57)=-4.249, p < .001, Cohen's d: 1.126, FDRC: .002). The participants within the 3D environment, however, felt more dominated than dominant compared to the treatment group (T(48.38) = 3.662, p < .001, Cohen's d: 1.053, FDRC: .002). Therefore, H2a and H2b can be confirmed as having a large effect size, and are thus supported, while H2c is rejected.[2]

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[2] To ensure a high reliability of the results, we also conducted a post-hoc experiment (10 in each group) with employees having an average age of 41.1 years and profound work experience. The descriptive results provide similar results (except for evidence that H2c is supported as participants in the treatment group feel less dominated than in the control group) as the main study from the perspective of more experienced participants (Details on descriptives can be found in Appendix 2). Moreover, also perceived usefulness and satisfaction are higher with the treatment group.

Participants' feelings of greater pleasure and arousal through the use of a 3D environment in our experiment provides evidence that learners can be engaged with the learning environment with a higher level of intrinsic motivation, in line with prior research (Baars et al., 2017; Parong and Mayer, 2018). Interestingly, in contrast to pleasure and arousal, the participants felt more dominated in the 3D environment. This may be due to the fact that participants of the treatment group were confronted with a new technological environment, whereas control group participants engaged with a familiar presentation method (Kalyuga and Liu, 2015). Thus, it becomes even more striking that participants had a better affective learning experience and scored higher in a shorter time even though they felt dominated within the new environment. The effect of 3D environment may become even more substantial when learners no longer experience extraneous cognitive load, once they have gotten used to the environment. This argument is supported by the results of the post-hoc test with older participants who did feel less dominated compared to the treatment group, hence their working experience seems to give them more confidence in using such systems.

To check whether there were differences among the groups with respect to the control measures, we applied either a *t*-test for normally distributed data or a Mann–Whitney *U* test for non-normal data. The control variables for modelling experience (U(426)=-.372, ns), job experience (U(420.5)=-0.444, ns), analytical–intuitive thinking (U(58)=-.140, ns) and global–local processing style (U(418)=-.528, ns) showed that there were no differences between the two groups. The tests also did not show any differences between the groups regarding participants' interest in understanding the process (T(58)=-1.520, ns), perceived cognitive load (U(440.5)=-.144, ns), and the time required for viewing the process (T(58)=-.750, ns).

Additionally, in order to increase the external validity of our experimental results, we conducted a quantitative online survey with 99 participants who worked within various shop-floor and service-related functions. Following the approach of Recker and Figl (2014), participants indicated their object–spatial ability as well as their preferences for 2D vs 3D environments using three example figures taken from the experiment design (on a scale from 1 = preference to 2D to 11 = preference to 3D) in the survey. Our results show that participants preferred 3D environments (6.5), were more satisfied with this form (6.6), and considered it more useful (6.7). The more evident their spatial ability, the more participants preferred the 2D environment (-.226, p = .025), were more satisfied with it (-.259, p = .01), and considered it more useful (-.233, p = .02), while participants with a higher object ability preferred 3D (.207, p = .037). The preferences for 3D ranged from 7.6 for participants in the lowest quartile of spatial ability to 5.3 for participants in the highest quartile of spatial ability. The results are independent of the age of participants, which ranged from 18 to 57. Overall, the results indicate participants' acceptance of, satisfaction with, and experienced usefulness of 3D environments of processes from the perspective of industrial shop-floor workers, and thus support our experimental results.

6. Limitations

This study has several limitations. We obtained results from one experiment with a between-groups design, despite adequate effect sizes, to conduct an experimental setting (Fritz et al., 2012). Moreover, while our quantitative survey serves to increase the external validity of our results within an industrial context, further experiments are needed using other processes in different industrial settings, as well as a greater number of cohorts, to enhance the generalisability of the results. Moreover, the effects need to be evaluated with reference to an interactive 3D environment.

While we observed an increase in recall arising from the use of a 3D environment, some factors need to be investigated further in order to clarify specific contributions and understand underlying mechanisms. First, novelty effects may have occurred; that is, it is possible that participants were more deeply engaged due to the novelty of the 3D environment situation, meaning that their improved recall may have been due to the novelty of the 3D representation. Second, there is a need to ascertain whether the visual context or the spatial location independently affect memory. The creation of an office in the 3D environment, while possessing very high utility for the intended process training application, provides both the visual context and spatial location in the training environment, and the increase in recall may have been due to a combination of both factors. Therefore, further experimentation is required to determine the dominant factor, or the ways in which both factors interact.

Our experiment is limited to testing immediate, and not long-term, recall. While immediate recall is often important in business contexts, since employees need to be prepared to work in relevant processes afterwards, certain processes do not occur often (e.g., contingency processes). Hence, further research is necessary to test recall effect a few months after training, without the interference of working in the relevant processes in the interim.

7. Conclusions

This paper describes the design, implementation, and evaluation of a non-interactive 3D virtual process visualisation to enhance process learning. The use of the method of loci as a memory recall enhancement in our proposed design provides theoretical support to enhance the formation of knowledge structures for office-based business processes. Theoretically, the approach can be used to train employees in different types of processes that take place in industrial organisations – those supporting production, as well as physical ones supporting manufacturing and logistical processes. This work does not claim to provide a commercial tool, but rather outlines a proof of concept for a new way of using 3D environments for process learning in the industrial context.

Our environment was evaluated through an experiment with 60 participants in a between-groups design. The environment showed improvements in the participants' activity recall while identifying correct connections in the process, speed of recall, and higher emotional impact towards the use of the non-interactive 3D environment approach, in comparison with the usage of a 2D environment.

Although practical applications of 3D environments are becoming widespread, their evaluation for general job training and their effects beyond basic efficiency measures remains scarce (Baars et al., 2017; Bosch-Sijtsema and Haapamäki, 2014). Our study expands prior research in industry by providing new insights into how 3D environments enhance results and how this knowledge can be used to set up a general training tool for information-based processes, and include motivational aspects beyond those of efficiency.

Another insight gained from our approach is that 3D environment solutions can be developed in a generalisable way to improve scalability, which is critical for the adoption of virtual and mixed environments in industry (Geng et al., 2020). Current approaches entail 3D environments that are primarily designed for specific learning material in a single domain (Mueller and Strohmeier, 2011). In contrast, our learning environment can be easily recreated for different domains in industry based on the process definitions available in the organisations. The approach is general enough to

be adapted into a tool for trainers with little or no programming, following the call for research by Borsci et al. (2015). A process model, annotated appropriately in XML using the BPMN format, can be imported into the tool and embedded into a 3D space that can be easily created using available marketplaces for 3D items (e.g., Unity Asset Store –– https://assetstore.unity.com/). Such resources have significantly reduced the costs of creating such 3D environments; our example cost less than $100. Additionally, new 3D scanning technologies, such as the Matterport (https://matterport.com/), enable the creation of virtual versions of real environments at a fraction of the cost of previous approaches. Therefore, the relative proportion of initial costs is much lower compared to training sessions organised for numerous employees with diverse backgrounds and learning prerequisites, especially in corporations with multiple branches. Therefore, we believe that our results may have important implications for how people are trained in gaining process knowledge in industrial settings. The environment can also be easily adapted to depict realistic visualisations of activities for shop-floor processes with distinguishable physical elements.

The promising results of this study open up opportunities for further research on the use of 3D environments for process training. Future research could investigate different design factors, such as visuals for process elements and traversal among activities, with regard to their separate effects on the acquisition of process knowledge. Furthermore, it is necessary to perform user studies in organisations to ascertain how laboratory results translate into a professional context. Lastly, virtual-reality and augmented-reality technologies, which offer greater levels of immersion and embodiment compared to 3D-environments on screens, can provide further opportunities to improve process training. Prior research has shown strong effects of placing experimental participants in virtual reality simulations for knowledge elicitation (Harman et al., 2017), and there is a need to examine whether these positive results can be replicated in a process training context.

CRediT authorship contribution statement

Michael Leyer: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing - original draft, Writing - review & editing. **Banu Aysolmaz:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing - original draft, Writing - review & editing. **Ross Brown:** Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Selen Türkay:** Investigation, Methodology, Writing - original draft, Writing - review & editing. **Hajo A. Reijers:** Methodology, Supervision, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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