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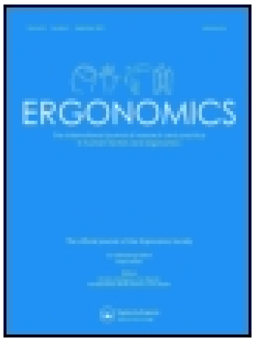

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A Framework of Knowledge Creation Processes in Participatory Simulation of Hospital Work Systems

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A Framework of Knowledge Creation Processes in Participatory Simulation of Hospital Work Systems

Participatory simulation (PS) is a method to involve workers in simulating and designing their own future work system. Existing PS studies have focused on analysing the outcome, and minimal attention has been devoted to the process of creating this outcome. In order to study this process, we suggest applying a knowledge creation perspective. The aim of this study was to develop a framework describing the process of how ergonomics knowledge is created in PS. Video recordings from three projects applying PS of hospital work systems constituted the foundation of process mining analysis. The analysis resulted in a framework revealing the sources of ergonomics knowledge creation as sequential relationships between the activities of simulation participants sharing work experiences; experimenting with scenarios; and reflecting on ergonomics consequences. We argue that this framework reveals the hidden steps of PS that are essential when planning and facilitating PS that aims at designing work systems.

Keywords: participative ergonomics; health care ergonomics; process mining; knowledge creation; work systems

Practitioner summary: When facilitating participatory simulation (PS) in work system design, achieving an understanding of the PS process is essential. By applying a knowledge creation perspective and process mining, we investigated the knowledge creating activities constituting the PS process. The analysis resulted in a framework of the knowledge creating process in PS.

1. Introduction

Designing new hospital workplaces does not only include design of the physical buildings. The physical building is tightly connected with how the work is organised, how workers communicate, how workers apply different technologies, and how workers conduct work tasks. These interconnected elements together form a hospital work system (Carayon et al. 2015; Hallock, Alper, and Karsh 2006; Holden et al. 2013). A work system has been defined as '…a system in which human participants and/or machines perform work using information, technology, and other resources to produce products and/or services for internal or external customers' (Alter 2006).

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The design of hospital work systems has been shown to influence healthcare workers' well-being and performance, resulting in impact on patient safety and quality of care (Hignett et al. 2013). Therefore, the design of hospital work systems has to support the work and the associated workers. Participatory ergonomics and simulation have been stated as two methods for designing work systems supporting the work and workers (Waterson et al. 2015). Participatory ergonomics involves workers in interventions and the design of their own future work system (van Eerd et al. 2010; Neumann and Village 2012; Xie, Carayon, Cox, et al. 2015). The advantage of PE is that the workers' knowledge of the existing work system contributes to the design of the new work system, and involvement of workers in the early design of work systems has shown financial benefits (Hendrick 2008). Simulation tools can have different forms, but always involve modelling the existing or the future work system (Hettinger et al. 2015). The advantage of simulation is that different work system designs can be evaluated, without the necessity for resource-demanding interference with the existing 'real world' work system. The rationale of both PE and simulation is that ergonomics challenges can be identified and improved during the design process, instead of being corrected after implementation, which often involves high costs.

A method combining the advantages of PE and simulation is participatory simulation (PS). PS is based on the principle that workers are involved in simulation of their future work system by application of simulation media that model the future work system (Daniellou 2007). The benefits of PS have been shown to be innovation of the future work system (Broberg and Edwards 2012); evaluation of the future ergonomics conditions (Andersen and Broberg 2015); detection and improvement of design properties that would lead to hazards or malfunctioning (Daniellou 2007); and smoothening of the implementation process (Daniellou 2007). The outcome of PS is often in the form of worker feedback that can function as new design specifications intended to be communicated to work system designers and integrated in the design (Barcellini, Van Belleghem, and Daniellou 2014; Béguin 2014; Broberg, Andersen, and Seim 2011; Daniellou 2007; Österman, Berlin, and Bligård 2016). The worker feedback has been shown to take several different forms (Österman, Berlin, and Bligård 2016), and is highly influenced by the fidelity of the simulation medium applied (Andersen and Broberg 2015).

This introduction to PS shows that the existing research has mainly focused on analysing the outcome of PS and not the process of creating this outcome. We argue that without understanding this process, we risk blindly planning and facilitating PS events. In the context of hospital work system design, it means that we remove hospital workers from their core area, for participating in PS events to create new design specifications, without really knowing the process we are planning and facilitating. Therefore, this study will investigate the process of PS. In order to do this, we suggest applying a knowledge creation perspective. In this way, we view PS as a process of creating new ergonomics knowledge in the form of new design specifications for the future work system to support both the human well-being and the overall system's performance.

1.1 Study aim

When applying a knowledge creation perspective to PS, we highlight how participating workers contribute with individual professional experiences, competences, and knowledge (Béguin

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2014; Daniellou 2007) to create new design specifications. The workers' professional knowledge is often difficult to put into words because it often has a 'tacit' nature and is thereby difficult to verbalise (Garrigou et al. 1995; Norros 2014). Norros (2014) indicates that PS and the application of objects such as simulation media is a relevant method for converting tacit knowledge into explicit knowledge. To shed light on this knowledge transformation and knowledge creation process of PS*, the aim of this study is to develop a framework describing the process of how ergonomics knowledge is created in PS.* We define a framework as a way of describing different elements and the general relationships among these elements (Ostrom 2011). We define a process as being a set of interrelated activities all contributing to a common goal. We define ergonomics knowledge as the outcome of PS in the form of new design specifications. The intention of the framework is to support ergonomists in planning and facilitating PS events.

1.2 The study context

The context of the study is hospital work system design. The outset is the current renewal process of the Danish hospitals, aiming at increasing efficiency and quality of care. Renewal of the hospital buildings includes building redesign and design of new hospital work systems to be employed in the new buildings. To assist the renewal process, the Danish Regional Councils have funded several innovation centres that involve healthcare workers from the existing hospitals in events that can be characterised as PS. The purpose is to benefit from the healthcare workers' professional knowledge of the existing hospital work systems to develop design specifications, and communicate these to the actors making design decisions about the new hospital work systems. These actors are hospital management, hospital planners, consulting architects, and consulting engineers. The PS phenomenon currently occurring in the Danish innovation centres provides a unique opportunity to investigate the creation of work system design specification in PS as a process of creating ergonomics knowledge.

2. Theoretical basis of knowledge creation

The knowledge creation perspective originates from organisational theory studies. Knowledge is defined as a 'mix of framed experiences, values, contextual information and expert insight…' (Davenport and Prusak 2000). The term *knowledge creation* has been applied in explanations of how companies could sustain innovative initiatives (Nonaka 1991). In this context, knowledge is recognised as a corporate asset of the organisation (Davenport and Prusak 2000). Knowledge creation has been defined as the process of converting individual tacit knowledge into explicit common knowledge and back again into tacit common knowledge in the organisation (Nonaka and Takeuchi 1995).

2.1 Participatory simulation from a knowledge creation perspective

Viewing PS as a knowledge creating process has not previously been introduced in the human factors and ergonomics field. Nevertheless, the knowledge creation perspective can bring a new frame of understanding to PS and other related participatory methods, because PS events include several of the same key elements as knowledge creation in an organisation

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does. In the following, we present three key elements and outline three assumptions that functioned as the initial frame of analysis of this study.

2.1.1 First key element: Interaction with objects in the form of simulation media

PS includes the application of and interaction with simulation media in the form of e.g. mock-ups, prototypes, and game boards that represent the initial design of the future work system (Daniellou 2007). These simulation media have been shown to fill the roles as mediators between the different participants (Béguin 2003; Broberg, Andersen, and Seim 2011; Daniellou 2007).

From a knowledge creation perspective, objects, such as the simulation media, have been shown to have the ability to mediate communication and sharing of knowledge between different actors, and thereby across boundaries (Carlile 2002). Furthermore, interaction with objects has been shown to foster new insights and ideas through the phenomenon of 'back-talk' (Schön 1983). 'Back-talk' happens when an actor interacts with or manipulates materials such as objects and then realises new insights based on the consequences of the interaction. The role of objects in knowledge creation in organisational studies may indicate that simulation media also have a role in knowledge creation in PS. Accordingly, our first initial assumption was that the activity of *interacting with objects in the form of simulation media* is a part of the knowledge creation process in PS.

2.1.2 Second key element: Engagement in tests and experiments

The simulation media are applied in what can be characterised as tests of different design scenarios of the future work system (Barcellini, Van Belleghem, and Daniellou 2014; Broberg, Andersen, and Seim 2011; Garrigou et al. 1995). The tests have been shown to be either *narrative*, where participants describe how the future work can be carried out in the new work system, or *experimental*, where participants act out the future work (Barcellini, Van Belleghem, and Daniellou 2014; Daniellou 2007).

From a knowledge management perspective, the tests can be related to the principles of reflective practice (Schön 1983) and of trial and error (Nonaka 1994). Reflective practice is an iterative process consisting of four iterative phases: framing the problem in a certain way, naming relevant factors of a situation, generating moves towards a solution, and reflecting on the outcomes of the moves (Schön 1983). Trial-and-error is a similar iterative process that happens when different actors combine their individual knowledge to develop new concepts through 'experimentation' (Nonaka 1994). The importance of experimenting in knowledge creation in organisational studies may also be important in knowledge creation in PS. Accordingly, our second initial assumption was that the activity of *engaging in tests in the form of experiments* is a part of the knowledge creation process in PS.

2.1.3 Third key element: Sharing knowledge in the form of experiences

Participating workers from different domains share perspectives and confront individual experiences (Broberg, Andersen, and Seim 2011; Garrigou et al. 1995; Xie, Carayon, Cartmill, et

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al. 2015). This has the consequences of conflicts, splitting, and negotiation (Béguin 2003; Taveira 2008) or shared awareness, consensus, and group decisions (Patel, Pettitt, and Wilson 2012; Taveira 2008; Xie, Carayon, Cartmill, et al. 2015).

From a knowledge management perspective, the sharing of perspectives and experiences can be related to the phenomenon of knowledge sharing. Knowledge sharing happens when individual and often tacit knowledge is converted into explicit and sharable knowledge, also called externalisation (Nonaka 1994). Knowledge can have different forms, where experiences are a central form. Experience is defined as 'what we have done and what has happened to us in the past' (Davenport and Prusak 2000), and is individual contextual knowledge. The importance of sharing knowledge, in the form of experiences, in the process of knowledge creation in organisations may also be important in the context of knowledge creation in PS. Accordingly, our third initial assumption was that the activity of *sharing knowledge by referring to work experiences* is a part of the knowledge creation process in PS.

3. Methods and procedures

We studied the PS events taking place in three different innovation centres, each related to a hospital renewal project in Denmark. These three projects were selected based on a maximum variation criterion (Flyvbjerg 2006) in relation to the PS types defined by the simulation medium. Thereby, the three projects applied three different simulation media: table-top models, full-scale mock-ups, and blueprints. The rationale of the maximum variation criterion was to strengthen findings of commonalities across the PS events of the three projects (Cresswell 2013). In this way, we sought to identify commonalities in the knowledge creation process across the three different PS types.

3.1 Procedures of the participatory simulations

The three projects and the PS types are summarised in Table 1, and the procedures for each PS type are presented in the following sections.

[Table 1]

3.1.1 Table-top simulations

The table-top simulations of the first hospital design project were initiated by the Danish Capital Region Innovation Centre, and were based on table-top models. The models consisted of A0-sized poster (33.1 x 46.8 in), where LEGO® figures and cardboard boxes were arranged; see Figure 1. The LEGO® figures depicted patients and healthcare professionals. The cardboard boxes illustrated rooms of the future outpatient department. The boxes were placed in different configurations to illustrate concepts for future building layout. The different layouts also included various ways of organising the work. The variety of layouts and work organisations were the foundations for each of the four PS events.

[Figure 1]

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The participating healthcare professionals from the existing outpatient department were selected by the department management. The goal was to include representatives from the three main employee groups. The healthcare professionals were the most active in the simulations, whereas the consultants and researchers were mainly observing and only occasionally participating.

The work tasks applied as scenarios were assigned simulation time as a third of real time. For simulating the scenarios, each of the participants was assigned a role and a LEGO® figure reflecting his or her professional background, and the group was supplied with egg timers for managing the simulation time of the scenarios. The participants moved the LEGO® figures around the table-top model and simultaneously drawing the movements on the A0-sized poster (33.1 x 46.8 in). After each scenario acting, the facilitator introduced a debriefing where the participants had the opportunity to discuss the insights obtained. This discussion often led to proposals of new work organisation or department layout in the form of a reconfiguration of the cardboard boxes, leading to yet another scenario being acted and so on.

The participants agreed on a concept for the future outpatient department layout and work organization. The notes and sketches documenting the concept were typed up as a part of a report intended to communicate the PS outcomes to architects, engineers, and other researchers in healthcare innovation.

3.1.2 Full-scale mock-up simulations

The full-scale mock-up simulations of the second hospital building project occurred in an innovation centre established by the owner of the hospital planning project. The mock-ups consisted of movable chipboard walls, large foam bricks, and standard hospital interior; see Figure 2. The mock-ups were constructed by the two centre employees prior to the PS events on the basis of architectural blueprints of hospital room proposals provided by the consulting architects.

[Figure 2]

The participating healthcare professionals were selected by the centre employees on the criteria of having worked in the rooms to be tested through full-scale mock-up simulations. The employees from the project owner organisation, and engineers and architects from the consulting companies, participated in order to contribute with technical insights.

The PS events started with an introductory meeting where the centre employees introduced the participants to the architectural room proposal. In the meeting, the participants discussed possible ergonomics challenges and work scenarios. The scenario acting and discussion in the subsequent full-scale mock-up simulation resulted in the centre employees adjusting the mock-ups and the participants retesting the mock-ups, iteratively leading to new adjustments.

The simulations continued until a room design supporting an ergonomic work system was obtained. Documenting sketches and descriptions of the agreed room design were

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intended to serve as an input to the project owner organisation, the engineers, and the architects managing the further hospital design.

3.1.3 Blueprint simulations

The blueprint simulations were part of an initiative of one of the Danish Regional Councils to establish a regional consulting service in the form of an innovation centre. The centre assisted in the process of moving into a new intensive care unit (ICU) by introducing blueprint simulation two months before the staff had to move into the new facilities. The blueprint simulations were based on A0-sized (33.1 x 46.8 in) blueprints of the future ICU including LEGO® figures, as illustrated in Figure 3. The blueprints were the final version of the new ICU layout designed by a team of architects and engineers. The LEGO® figures depicted patients and healthcare professionals at the ICU.

[Figure 3]

The participating healthcare professionals were selected by the ICU management based on the criteria of involving healthcare professionals from the five main employee groups.

The applied scenarios stated typical work situations, e.g. two patients are unrestful and require attention, though it is time for the morning meeting for the nurses; what would you do? The scenarios triggered the participants to visualise the situation by applying the blueprint and the LEGO® figures. To solve the scenarios, the participants discussed and tested different possible solutions by moving the LEGO® figures around on top of the blueprint. The participants' discussions and acting of scenarios led to new questions and challenges, which iteratively encouraged new discussions and acting.

The blueprint simulation resulted in the participants agreeing on new ways of organising the work practices and the work systems. The participants' notes on the new organization and work practices intended to serve as input for the ICU management, architects, and engineers.

3.2 Data collection

The data collected were based on video recordings of the PS events. The first author observed and recorded the full-scale mock-up simulations and the blueprint simulations. The second author observed, occasionally participated in, and recorded the table-top simulations. Video was recorded by applying a fixed camera with the purpose of acquiring a distant view of the PS events, and thereby recording the interactions of the different participants (Heath, Hindmarsh, and Luff 2010). An advantage of the fixed camera was also that the camera drew less attention from the simulation participants.

3.3 Data analysis

The data analysis was based on three steps, as illustrated in Figure 4. The three steps are elaborated in the following three sections.

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[Figure 4]

3.3.1 Video coding

In the first analysis step, we applied the three assumed knowledge creation activities of PS defined in Section 2.1 as a frame of analysis in the form of an initial coding protocol. The video recordings of the first PS events of each of the three hospital design projects were coded in order to identify the video segments in which participants engaged in the three activities. The coded video segments were transcribed as a combination of both audio and visual conduct (Heath, Hindmarsh, and Luff 2010). The transcriptions were subsequently thoroughly examined to evaluate the initial coding protocol. From that examination, the initial coding protocol was expanded to five main activities and thirteen sub-activities as illustrated in Figure 4 and presented in Appendix A. The expanded coding protocol was applied in the coding of the remaining video recordings. This resulted in a total of 3,415 coded video segments.

3.3.2 Process mining

In the second analysis step, we applied process mining to explore the relations between the thirteen sub-activities identified in the first analysis step. Process mining is related to process analysis, which is the study of processes from a view of what is really happening and not from the view of predefined procedures (van der Aalst and Weijters 2005). Process mining is based on the utilisation of data from event-logs (van der Aalst and Weijters 2005). Event-logs refer to information systems that companies use to manage business processes. These systems include retrospective data on the conducted activities in relation to specific business processes, where each process instance is described as a case. The data are based on timestamps, consisting of a start- and end-time of each conducted activity per case. In this study, we expanded the understanding of event-logs to include our coding of the video recordings. The coded video segments were all described by a sub-activity and a timestamp. Furthermore, each coded video segment was part of one of the 12 PS events defined as cases. This left us with 12 cases and a list of sub-activities per case including timestamps.

In process mining, the cases in the form of sub-activities and timestamps are combined into a process map illustrating a 'representative' of the behaviour seen in the event-log (van der Aalst 2011). This map is created through the analysis of patterns of activities across the cases. The patterns involve both the sequence of activities and whether activities happen at the same time. Consequently, if activity B often happens after activity A or if activity B often happens at the same time as A, a causal dependency is assumed and a connection is visualised in the process map (van der Aalst 2011). For creating the process map, we applied the software Disco® by Fluxicon (Eindhoven, The Netherlands). From the 12 PS events of sub-activities and timestamps, we created a process map of the sub-activities representing the knowledge creation process across the 12 PS events. The process map is illustrated in the second analysis step in Figure 4. This process map shows a nest of connections in the form of sequential relationships between the sub-activities.

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3.3.3 Simplification of process map

In the third step of analysis, we applied the principles of aggregation and abstraction (Günther and van der Aalst 2007) to simplify the process map. Aggregation is intended to 'limit the number of information items displayed' in the process map (Günther and van der Aalst 2007). This was done by clustering the sub-activities that were related to the same main activity. Abstraction is to omit information that is 'insignificant in the chosen context' (Günther and van der Aalst 2007). This was done by omitting connections that had low frequency. The frequencies of the connections between the sub-activities are presented in Appendix B. We chose to omit connections with a frequency constituting less than 1.3% of the total number of frequencies of the connections between all sub-activities. In addition, we also left out the repetition connections, in the sense of self-looping of sub-activities.

Furthermore, we investigated which sub-activities occurred at the same time. These were identified per case through the analysis of overlap of the time-stamps and are presented in Appendix C. The sub-activities, having overlaps constituting more than 4.4% of the total number of overlaps between all sub-activities, were visually indicated on the simplified process map. The simplification of the process map resulted in a framework (Ostrom 2011) describing the knowledge creation process across the 12 PS events as illustrated in the third step of analysis in Figure 4.

4. A framework of knowledge creation in participatory simulation

The developed framework is presented in Figure 5. The framework includes five main activities and eight sub-activities. The frequencies of the connections, in the form of sequential relationships, are indicated by the thickness of the arrows. The frequency of each connection is described as a percentage of the total number of frequencies of the connections between all of the sub-activities in the process map. Some sub-activities often occurred at the same time and thereby did not constitute a sequence. This is visualised as dashed boxes in the framework. In the following sections, we review the framework, provide empirical examples of central sequential relationships, and interpret these in relation to the knowledge creation perspective.

[Figure 5]

4.1 The relationship between 'asking other participants', 'explaining own work', and 'what-if discussions'

The activity, *sharing work experiences*, had two dominating sub-activities: *asking other participants* and *explaining own work*. The *explaining own work* led to *what-if discussions*, which were a sub-activity of the *experimenting*. In the *what-if discussions* participants discussed future scenarios related to how to design the new hospital work system. The discussions often started with 'what if…' and were focusing on either the physical elements of the work system, e.g. buildings or interior positioning, or organisational aspects of the work system, e.g. how to divide work. An example of the sequential relationship between the three

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sub-activities is presented in Table 2.

[Table 2]

4.1.1 'Explaining own work' as knowledge externalisation

The relationship between the *explaining own work* and *what-if discussions* had a high frequency. Thereby, *explaining own work* can be seen as a trigger of *what-if discussions*. To enable this triggering, the shared work experiences from the *explaining own work* had to be understandable to other participants. To be understandable, the work experiences in the form of individual knowledge had to be explicit, which implied externalisation of the individual knowledge (Nonaka 1994). Thereby, when participants externalised their individual work experiences, they started engaging in experiments in the form of *what-if discussions* based on the externalisations.

4.2 The relationship between 'acting scenarios', 'physically testing and interacting', and 'what-if discussions'

The *experimenting* activity had two sub-activities: *acting scenarios* and *what-if discussions*. In the *acting scenarios*, participants acted out scenarios that had been defined beforehand or that continually developed during the PS events. The acting was in contrast to the *what-if discussions* in which participants discussed the scenarios but did not perform them. The *acting scenarios* often happened at the same time as participants were *physically testing and interacting* with the simulation medium, leading to *what-if discussions*. An example of this sequential relationship between the three sub-activities is presented in Table 3.

[Table 3]

4.2.1 'Experimenting' for combining externalised knowledge

The *physically testing and interacting* sub-activity was shown to be the link between the *acting scenarios* and *what-if discussions*. The relationship between these three sub-activities was shown to be bidirectional, meaning that the *acting scenarios* and *what-if discussions* occurred in iterations. The iterations related to the trial-and-error processes (Nonaka 1994) based on actors engaging in experiments and combined their externalised knowledge into new concepts (Nonaka 1994). Thereby, the iterative *experimenting* was a process in which the participants combined their externalised knowledge.

4.3 The relationship between 'what-if discussions', 'pointing', and 'physically testing and interacting'

What-if discussions were a sub-activity of *experimenting*, and happened often at the same time as the *pointing*, which was a sub-activity of *interacting with simulation medium*. In this way, the participants applied the simulation medium in their discussions by pointing at different parts of the medium. The discussions and pointing led to the participants' *physically*

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testing and interacting with the simulation medium by grasping and moving parts. *Physically testing and interacting* was the second sub-activity of *interacting with simulation medium*. The interactions were shown to foster new *what-if discussions*. As a result, an iterative loop between these three sub-activities was identified, and an example is presented in Table 4.

[Table 4]

4.3.1 Two modes of simulation media interaction for knowledge combination

Pointing and *physically testing and interacting* were two modes of simulation media interaction. Each of them happened at the same time as each of the sub-activities of *experimenting*, as indicated with dashed boxes in the framework. *Experimenting* was the activity of participants combining externalised knowledge. To achieve this, participants had to communicate. Relating to the mediating abilities of objects (Carlile 2002), the simulation medium and the two modes of interaction can be seen as central resources for the communication between the participants having different professional backgrounds. Thereby, the modes of interactions are also resources for the combination of externalised knowledge.

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4.4 The relationship between 'what-if discussions', 'addressing ergonomics consequences', 'pointing', and 'formulating joint design specifications'

The *what-if discussions* led to *addressing ergonomics consequences*, which were a sub-activity of *reflecting*. The *addressing ergonomics consequences* happened when participants assessed and evaluated the ergonomics consequences of the scenario explored in the *what-if discussions*. At the same time, as the participants were *addressing ergonomics consequences*, they were *pointing* at parts of the simulation medium. Often, the *addressing ergonomics consequences* led backwards to the *what-if discussions*, resulting in an iterative loop. However, sometimes this loop led to *formulating joint design specifications*, which was a sub-activity of *proposing new design*. In the *formulating joint design specifications*, participants were together agreeing on and defining design specifications for the future hospital work system. Two different types of design specifications were identified. The first type consisted of tangible and precise design suggestions, e.g. specific placement of patients or interiors. The second type involved less tangible focus points, e.g. possible challenges about light inflow or psychosocial stress. The tangible design suggestions had the purpose of guiding the work system design, where the focus points were intended as challenges to be taken into account in the design. An example of the sequential relationship between the four sub-activities is presented in Table 5.

[Table 5]

4.4.1 Experiment-reflection loop as reflective practice in knowledge creation

The identified loop between *what-if discussions* and *addressing ergonomics consequences* shows an experiment-reflection loop. This loop relates to the third and fourth phases of reflective practice (Schön 1983): *generating* moves towards a solution and *reflecting* on the

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outcomes. Here, the *what-if discussions* are discussions of possible design moves towards an ergonomic work system design, and *addressing ergonomics consequences* involves the reflections on the consequences of these possible design moves. The *pointing*, taking place at the same time as *addressing ergonomics consequences*, can be related to the phenomenon of 'back-talk' (Schön 1983), where the participants' interactions with the simulation media are a resource for realising and reflecting on the ergonomics consequences. The frequency of the loop between the *what-if discussions* and the *addressing ergonomics consequences* was the highest compared with the other connections in the framework. Thereby, the reflective practice was a core part of the knowledge creation process in the PS activities.

4.4.2 The jointly created ergonomics knowledge

The experiment-reflection loop was shown to develop into participants *formulating joint design specifications*, which we see as the created knowledge. However, the frequency of the connection from *addressing ergonomics consequences* to *formulating joint design specifications* was observed to be relatively low compared with the frequencies in the experiment-reflection loop. Investigation of the low frequency revealed that when participants were *addressing ergonomics consequences*, they engaged in *what-if discussions* on several different ways of redesigning the work system in order to address the negative consequences. This resulted in addressing challenges, which led to new *what-if discussion*. The participants engaged in several iterations before they reached an agreement and formulated joint design specifications. Thereby, the knowledge created in PS is a result of comprehensive experiment-reflection loops.

5. Discussion

The developed framework describes the sub-activities and sequential relationships constituting the knowledge creation process in participatory simulation (PS) of hospital work systems. The intention of the framework was to support ergonomists in planning and facilitating PS events. The framework supports this planning by revealing the activities and sub-activities constituting the knowledge creation process of PS. Thereby, the ergonomist knows which activities to plan for. The planning includes selection of simulation medium to support both modes of media interaction; preparation of scenarios to support both types of experiments; and selection of participants with relevant professional experiences. The framework supports facilitation by revealing the connections between the sub-activities constituting the knowledge creation process of PS. The connections show which sub-activities form sequences leading to the created knowledge in the form of *formulating joint design specifications*. In the facilitation, the ergonomist then knows which activities to encourage and monitor in order to create new ergonomics knowledge. In this way, the framework reveals the previous hidden steps of the knowledge creation process in PS. In the following sections, we will discuss the contributions and further research of this study.

5.1 The knowledge creation perspective and the process mining method

Existing ergonomics studies have addressed and applied the principles of experiential learning

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and knowledge sharing (e.g. Béguin 2003; Neumann, Dixon, and Ekman 2012; Garrigou et al. 1995), which relate to knowledge creation. However, viewing participatory activities such as PS as knowledge creation processes has not previously been introduced in the ergonomics field. The present study thereby contributes by showing how the theoretical knowledge creation perspective assists in drawing attention to the sub-activities of the PS process.

Several ergonomics studies have introduced a system perspective based on interconnected elements (e.g. Carayon et al. 2015; Hallock, Alper, and Karsh 2006) that relate to the process mining method. Despite the commonalities, process mining is still a novel method in the ergonomics field. In this study, the process mining supplemented the knowledge creation perspective by showing the connections between the knowledge creation activities, and thereby contributes by revealing the hidden steps of the PS process. Furthermore, the process mining provided an opportunity for conducting a deep and thorough empirical analysis.

5.2 The variations between the PS events

The PS events investigated in this study applied different simulation media, scenarios, and facilitation styles, and involved different types of participants. The possible influences of the variations are discussed in the following sections.

5.2.1 The simulation medium

The fidelity of the simulation medium has been shown to influence PS outcome (Andersen and Broberg 2015; Bligård, Österman, and Berlin 2014). Furthermore, simulation participants are known to prefer some media over others (Österman, Berlin, and Bligård 2016). Based on this, the simulation media in this study might have influenced the knowledge creation process, especially in relation to the two modes of media interaction. However, when comparing the three types of PS in relation to the two modes of interaction, we could not identify a clear pattern of difference. This could mean that the three simulation media all supported both modes of interaction. However, we will emphasise that this does not necessarily mean that the medium does not matter when creating ergonomics knowledge. The medium should still support both modes of interaction, e.g. blueprints without LEGO® figures would not give rise to participants grasping and moving parts in the *physically testing and interacting* activity. This might also be the reason for simulation participants rating 2D blueprints as less preferable than full-scale mock-ups, which afford the *physically testing and interacting* activity to a greater extent (Österman, Berlin, and Bligård 2016).

5.2.2 The scenarios and the facilitation style

The scenarios and the facilitation in the PS events were related. When scenarios were applied as outset for the PS, the events were facilitated in an open manner. When scenarios were applied as manuscripts, a more directed facilitation style was applied. Existing studies on scenario application show that scenarios stimulate ideation (Carroll 2000), and existing studies on facilitation of simulation in education show that the facilitation style influences

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participants' educational profit (Clapper 2014). Therefore, the scenarios and facilitation style of the PS in this study might have influenced the knowledge creation process. We expected the influence in relation to the two types of *experimenting*: *acting scenarios* and *what-if discussions*. Both rely on scenarios and require facilitation in different ways. When comparing the knowledge creation process of the three PS types, a small excess of *acting scenarios* happened in the table-top simulation, which applied scenarios as manuscripts and had a more directed facilitation style. However, the *what-if discussions* still occurred and resulted in experiment-reflection loops. This indicates that a scenario's application and facilitation style might influence the type of experiments taking place in PS. Furthermore, we suggest that further research be conducted on the influence of scenarios and facilitation on the knowledge creation process of PS.

5.2.3 The simulation participants

The simulation participants of the different PS events varied. Existing studies indicate that some participants are more skilled than others in engaging in participatory processes (von Hippel 2009; Reuzeau 2001). Therefore, the differences of participants might have influenced the knowledge creation process. In some events, the diversity of the participants in relation to their professional background was limited. This was especially true in relation to the full-scale mock-ups. A low diversity could have resulted in fewer shared work experiences because the participants already knew each other's work due to their mutual professional background. We expected to see this in the *asking other participants* and *explaining own work* activities. However, the analysis did not show a clear pattern of difference between the PS events of low and high participant diversity. Nevertheless, we have to take into account that the involvement of workers in work system design has been a tradition in Scandinavia and workers are thereby culturally prepared for engaging in participatory processes. This might be different in other national contexts, and requires further research.

5.3 Limitations and transferability

This study is based on three hospital design projects consisting of 12 PS events. This yielded an in-depth understanding of these specific findings, limiting the generalisability of the study (Thomas 2011). However, Flyvbjerg (2006) argues that cases, such as the 12 PS events, can be examples to learn from. The learning can enable transferability of parts of the findings to other contexts with similar characteristics (Guba 1981). The PS events of this study contribute to the design of hospital work systems, which are socio-technical systems with a complex nature (Hignett et al. 2013). Thereby, other socio-technical-based contexts may have the same characteristics and can thereby draw from the PS framework of this study, e.g. service systems design.

6. Conclusion

The aim of this study was to develop a framework describing the process of how ergonomics knowledge is created in participatory simulation (PS). Based on three different types of PS in

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three hospital design projects, we applied a knowledge creation perspective and the process mining method. The theoretical perspective and the method resulted in a new understanding of PS in the ergonomics field. The analysis of the PS events resulted in a framework revealing five activities and six sub-activities connected in overlaps and sequential relationships, constituting the knowledge creation process of PS. The most central activities were *sharing work experiences*, *experimenting*, *interacting with simulation medium*, and *reflecting*. These activities led to the creation of ergonomics knowledge in the form of participants formulating joint design specifications with the aim of designing a future work system supporting both human well-being and overall system performance.

The framework reveals the hidden steps of the PS process. Understanding of these steps is central when ergonomists plan and facilitate PS aiming at the design of ergonomics work systems. Therefore, based on the developed framework, we have formulated four implications for practitioners to take into account when planning and facilitating PS:

- It is important to encourage simulation participants to explain their own work to foster externalisation of their work experiences. Sharing of work experiences leads to engagement of participants in experiments addressing how to design an ergonomic work system.
- PS should be planned to include experiments in the form of both scenario acting and what-if discussions. Scenario acting often leads to what-if discussions; therefore, both types of experiments are needed in the knowledge creation process.
- The simulation medium should be selected to support both types of experiments. In the acting of scenarios, the medium should provide the participants the opportunity for grasping and moving parts. In what-if discussions, the medium should provide the participants the opportunity for pointing at parts that are the focus of the discussion.
- It is important to introduce opportunities for participants to reflect on the ergonomics consequences of the experiments. Such reflections are an essential step towards the creation of ergonomics knowledge in the form of joint design specifications.

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Appendix A

The extended coding protocol applied to the video recordings of the 12 participatory simulation PS events is presented in Table A1.

[Table A1]

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Appendix B

In Table B1, the frequencies of connections in the form of sequential relationships between the 13 sub-activities are displayed. An example from the table is *what-if discussions* (the 4th column) led to *addressing ergonomics consequences* (the 11th row). The frequency of that connection was 6.57% of the total number of sequences. This was the most frequent sequential relationship identified between the sub-activities.

[Table B1]

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Appendix C

Table C1 shows the overlap of timestamps between the 13 sub-activities and thereby which sub-activities often took place at the same time. An example from the table is that the overlap between *pointing* (the 4th column and row) and *what-if discussions* (the 2nd column and row) constituted 11.19% of the total number of overlaps. This was the highest number of overlaps identified between the sub-activities.

[Table C1]

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References

Alter, Steven. 2006. "Work Systems - The Source of Business Results." In *The Work System Model - Connecting People, Processes and IT for Business Results*, First, 9–20. Larkspur: Work System Press.

Andersen, Simone N., and Ole Broberg. 2015. "Participatory Ergonomics Simulation of Hospital Work Systems: The Influence of Simulation Media on Simulation Outcome." *Applied Ergonomics* 51: 331–342. doi:10.1016/j.apergo.2015.06.003.

Barcellini, Flore, Laurent Van Belleghem, and François Daniellou. 2014. "Design Projects as Oppotunities for the Development of Activities." In *Constructive Ergonomics*, edited by Pierre Falzon, 187–205. Taylor & Francis.

Béguin, Pascal. 2003. "Design as a Mutual Learning Process between Users and Designers." *Interacting with Computers* 15 (5): 709–730. doi:10.1016/S0953-5438(03)00060-2.

———. 2014. "Learning during Design through Simulation." In *11th International Symposium on Human Factors in Organisational Design and Management & 46th Annual Nordic Ergonomics Society Conference*, 867–872. Copenhagen: IEA.

Bligård, Lars-Ola, Cecilia Österman, and Cecilia Berlin. 2014. "Using 2D and 3D Models as Tools during a Workplace Design Process - A Question of How and When." In *11th International Symposium on Human Factors in Organisational Design and Management & 46th Annual Nordic Ergonomics Society Conference*, 799–804. Copenhagen: IEA.

Broberg, Ole, Vibeke Andersen, and Rikke Seim. 2011. "Participatory Ergonomics in Design Processes: The Role of Boundary Objects." *Applied Ergonomics* 42 (3): 464–472. doi:10.1016/j.apergo.2010.09.006.

Broberg, Ole, and Kasper Edwards. 2012. "User-Driven Innovation of an Outpatient Department." *Work - A Journal of Prevention, Assessment & Rehabilitation* 41 (1): 101–106. doi:10.3233/WOR-2012-0142-101.

Carayon, Pascale, Peter Hancock, Nancy Leveson, Ian Noy, Laerte Sznelwar, and Geert van Hootegem. 2015. "Advancing a Sociotechnical Systems Approach to Workplace Safety – Developing the Conceptual Framework." *Ergonomics* 58 (4): 548–564. doi:10.1080/00140139.2015.1015623.

Carlile, Paul. 2002. "A Pragmatic View of Knowledge and Boundaries : Boundary Objects in

New Product Development." *Organization Science* 13 (4): 442–455.

Carroll, John. 2000. "Five Reasons for Scenario-Based Design." *Interacting with Computers* 13 (1). HICSS '99: 43–60.

Clapper, Timothy C. 2014. "Situational Interest and Instructional Design: A Guide for Simulation Facilitators." *Simulation & Gaming* 45 (2) (January 27): 167–182. doi:10.1177/1046878113518482.

Cresswell, John. 2013. "Data Collection." In *Qualitative Inquiry and Research Design*, 3rd ed., 145–180. SAGE Publications Ltd.

Daniellou, François. 2007. "Simulating Future Work Activity Is Not Only a Way of Improving Workstation Design." *@ctivités* 4 (2): 84–90.

Davenport, Thomas, and Laurence Prusak. 2000. *Working Knowledge: How Organizations Manage What They Know*. Boston: Harvard Business School Press.

Flyvbjerg, Bent. 2006. "Five Misunderstandings About Case-Study Research." *Qualitative Inquiry* 12 (2): 219–245. doi:10.1177/1077800405284363.

Garrigou, Alain, François Daniellou, Gabriel Carballeda, and Sylvain Ruaud. 1995. "Activity Analysis in Participatory Design and Analysis of Participatory Design Activity." *International Journal of Industrial Ergonomics* 15 (5): 311–327. doi:10.1016/0169-8141(94)00079-I.

Guba, Egon G. 1981. "Criteria for Assessing the Trustworthiness of Naturalistic Inquiries." *Educational Communication & Technology* 29 (2): 75–91. doi:10.1007/BF02766777.

Günther, Christian, and Wil M. P. van der Aalst. 2007. "Fuzzy Mining – Adaptive Process Simplification Based on Multi-Perspective Metrics." In *Lecture Notes in Computer Science: Business Process Management*, 4714:328–343. doi:10.1007/978-3-540-75183-0.

Hallock, Melissa, Samuel Alper, and Ben-Tzion Karsh. 2006. "A Macro-Ergonomic Work System Analysis of the Diagnostic Testing Process in an Outpatient Health Care Facility for Process Improvement and Patient Safety." *Ergonomics* 49 (5): 544–566.

Heath, Christian, Jon Hindmarsh, and Paul Luff. 2010. *Video in Qualitative Research*. London: SAGE Publications Ltd.

Hendrick, Hal W. 2008. "Applying Ergonomics to Systems: Some Documented 'Lessons

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Learned.'" *Applied Ergonomics* 39: 418–426. doi:10.1016/j.apergo.2008.02.006.

Hettinger, Lawrence, Alex Kirlik, Yang Miang Goh, and Peter Buckle. 2015. "Modelling and Simulation of Complex Sociotechnical Systems: Envisioning and Analysing Work Environments." *Ergonomics* 58 (4): 600–614. doi:10.1080/00140139.2015.1008586.

Hignett, Sue, Pascale Carayon, Peter Buckle, and Ken Catchpole. 2013. "State of Science: Human Factors and Ergonomics in Healthcare." *Ergonomics* 56 (10) (January): 1491–503. doi:10.1080/00140139.2013.822932.

Holden, Richard, Pascale Carayon, Ayse Gurses, Peter Hoonakker, Ann Schoofs Hundt, A. Ant Ozok, and A. Joy Rivera-Rodriguez. 2013. "SEIPS 2.0: A Human Factors Framework for Studying and Improving the Work of Healthcare Professionals and Patients." *Ergonomics*. Taylor & Francis. doi:10.1080/00140139.2013.838643.

Neumann, Patrick, Shane M. Dixon, and Marianne Ekman. 2012. "Ergonomics Action Research I: Shifting from Hypothesis Testing to Experiential Learning." *Ergonomics* 55 (10) (October): 1127–1139. doi:10.1080/00140139.2012.700327.

Neumann, Patrick, and Judy Village. 2012. "Ergonomics Action Research II: A Framework for Integrating HF into Work System Design." *Ergonomics* 55 (10): 1140–1156. doi:10.1080/00140139.2012.706714.

Nonaka, Ikujiro. 1991. "The Knowledge Creating Company." *Harvard Business Review* 69 (6): 96–104. doi:10.1016/0024-6301(96)81509-3.

———. 1994. "A Dynamic Theory of Organizational Knowledge Creation." *Organization Science* 5 (1): 14–37. doi:10.1287/orsc.5.1.14.

Nonaka, Ikujiro, and Hirotaka Takeuchi. 1995. "Theory of Organizational Knowledge Creation." In *The Knowledge Creating Company*, 56–94. Oxford University Press.

Norros, Leena. 2014. "Developing Human Factors/ergonomics as a Design Discipline." *Applied Ergonomics* 45 (1) (January): 61–71. doi:10.1016/j.apergo.2013.04.024.

Ostrom, Elinor. 2011. "Background on the Institutional Analysis and Development Framework." *Policy Studies Journal* 39 (1): 7–27. doi:10.1111/j.1541-0072.2010.00394.x.

Patel, Harshada, Michael Pettitt, and John R. Wilson. 2012. "Factors of Collaborative Working: A Framework for a Collaboration Model." *Applied Ergonomics* 43 (1): 1–26.

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doi:10.1016/j.apergo.2011.04.009.

Reuzeau, Florence. 2001. "Finding the Best Users to Involve in Design: A Rational Approach." *Le Travail Humain* 64 (3): 223–245.

Schön, Donald A. 1983. *The Reflective Practitioner*. Basic Books.

Taveira, Alvaro D. 2008. "Key Elements on Team Achievement: A Retrospective Analysis." *Applied Ergonomics* 39 (4): 509–518. doi:10.1016/j.apergo.2008.02.007.

Thomas, Gary. 2011. *How to Do Your Case Study: A Guide for Students and Researchers*. London: SAGE Publications.

van der Aalst, Wil M. P. 2011. "Process Discovery: An Introduction Process." In *Process Mining: Discovery, Conformance and Enhancement of Business Processes*, 125–156. Springer. doi:10.1007/978-3-642-19345-3.

van der Aalst, Wil M.P., and A.J.M.M. Weijters. 2005. "Process Mining." In *Process-Aware Information Systems: Bridging People and Software through Process Technology*, 235–255. Wiley & Sons. doi:10.1002/0471741442.ch10.

van Eerd, Dwayne, Donald Cole, Emma Irvin, Quenby Mahood, Kiera Keown, Nancy Theberge, Judy Village, Marie St Vincent, and Kim Cullen. 2010. "Process and Implementation of Participatory Ergonomic Interventions: A Systematic Review." *Ergonomics* 53 (10): 1153–1166. doi:10.1080/00140139.2010.513452.

von Hippel, Eric. 2009. "Democratizing Innovation: The Evolving Phenomenon of User Innovation." *International Journal of Innovation Science* 1 (1) (March 1): 29–40. doi:10.1260/175722209787951224.

Waterson, Patrick, Michelle M. Robertson, Nancy J. Cooke, Laura Militello, Emilie Roth, and Neville A. Stanton. 2015. "Defining the Methodological Challenges and Opportunities for an Effective Science of Sociotechnical Systems and Safety." *Ergonomics* 58 (4): 565–599. doi:10.1080/00140139.2015.1015622.

Xie, Anping, Pascale Carayon, Randi Cartmill, Yaqiong Li, Elizabeth D. Cox, Julie A. Plotkin, and Michelle M. Kelly. 2015. "Multi-Stakeholder Collaboration in the Redesign of Family-Centered Rounds Process." *Applied Ergonomics* 46: 115–123. doi:10.1016/j.apergo.2014.07.011.

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Xie, Anping, Pascale Carayon, Elizabeth D. Cox, Randi Cartmill, Yaqiong Li, Tosha B. Wetterneck, and Michelle M. Kelly. 2015. “Application of Participatory Ergonomics to the Redesign of the Family-Centered Rounds Process.” *Ergonomics* (April 2015): 1–49. doi:10.1080/00140139.2015.1029534.

Österman, Cecilia, Cecilia Berlin, and Lars-Ola Bligård. 2016. “Involving Users in a Ship Bridge Re-Design Process Using Scenarios and Mock-up Models.” *International Journal of Industrial Ergonomics* 53: 236–244. doi:10.1016/j.ergon.2016.02.008.

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Tables with captions

Table 1. The three hospital design projects applying PS.

PS type	Aim of application of PS	PS events	Types of participants	Application of scenarios	Facilitators	Facilitation style	Documentation of PS outcome
Table-top simulation	Apply PS to contribute to design of a new outpatient department building at a major hospital and test simulation methods in healthcare innovation.	4 PS events with duration from 1.5 hours to 2 hours.	Chief surgeon, physician, nurses, medical secretaries, consultants from industry, researchers in ergonomics.	Developed beforehand by the management and the facilitator including a list of work tasks, including simulation time of each task.	Clinical simulation consultant.	The facilitator solely directed the PS.	Participating researcher sketched the agreed department layout and took notes on the agreed organisation.
Full-scale mock-up simulation	Apply PS to test standard room proposals for a major new hospital intended to replace two existing hospitals. The testing was intended to inform the architectural design process.	4 PS events with duration from 45 minutes to 1 hour.	Medical secretaries, executive medical secretaries, executive nurses, staff members from hospital management, staff members from project division, IT consultants, hospital orderlies, technical department employees, architects, engineers.	Identified in an introductory meeting and continually developed by the PS participants during the PS events.	Centre facilitators with occupational health and safety background, and clinical background.	Facilitation in an open manner where the facilitators were cautious, and encouraged the participants to take initiative.	Centre facilitators sketched the agreed room layout and took notes to form a description
Blue-print simulation	Apply PS for supporting the process of moving into a renovated intensive care unit at a small hospital and contributing to design of the work system planned to take place in the new facilities.	4 PS events with duration of 2 hours.	Nurses, coordinating nurses, physiotherapists, service assistants, medical secretaries, occupational therapists, charge nurses.	Developed beforehand by the work practice development nurse, and were applied as an outset of the PS events.	Work practice development nurse, facilitator from region.	Facilitation in an open manner where the facilitators were cautious time managers, and encouraged the participants to take initiative.	Simulation participants took turns in taking notes.

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Table 2. Example of the sequential relationship between *asking other participants*, *explaining own work,* and *what-if discussions*.

<table>
<tr><td colspan="3">From blueprint simulation PS events 1

The scenario simulated is how a nurse, assigned to receive a new patient, can manage to prepare medication for the patient. The medication has to be prepared in the medication room located in one part of the ICU. The new patient is placed in another location of the ICU. The challenge is that the nurse has to constantly monitor the new patient, meaning that the nurse cannot leave the patient to travel to the medication room.</td></tr>
<tr><td>Asking other participants</td><td>Physiotherapist:</td><td>Addresses a question to the participating coordinating nurse 1: ‘Can you leave the [bed]room now?’</td></tr>
<tr><td>Explaining own work</td><td>Coordinating nurse 1:

Coordinating nurse 2:</td><td>‘No, I can’t…’

‘I don’t think we should be the only one to receive. The way we do it now is that we allocate two persons’ (Refers to the fact that one of the persons can leave the room to prepare medication)</td></tr>
<tr><td>What-if discussions</td><td>Coordinating nurse 1:

Nurse:

Coordinating nurse 1:</td><td>‘What if one [nurse] from one of the good [less urgent] patients could take over here? And then I could go’

‘Then the coordinator could look after the good patient [in the meantime]’

‘Yes, you cannot take care of the most complicated [patient] and be coordinator [at the same time]’</td></tr>
</table>

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Table 3. Example of the sequential relationship between *acting scenarios*, *physically testing and interacting,* and *what-if discussions*.

From table-top simulation PS event 3 In this simulation example, the intention is to reduce the number of times a patient has to move between rooms in the outpatient department. In the existing department, the patient moves from the waiting area to the physician in the examination room and to the nurse in the conversation room. In this scenario, the patient goes directly to a free examination room when arriving to the department. Furthermore, the physician and nurse do not have settled rooms, but move from room to room, and thereby from patient to patient.		
Acting scenarios, *Physically testing and interacting*		*An egg-timer rings.*
	Medical secretary: (acting patient)	'Now I'm done'
	Physician: (acting physician)	'Then I say goodbye, and then I go out here and start writing' *Moves the LEGO® figure out of the examination room (cardboard box) into the staff area on the A0-sized poster (33.1 x 46.8 in).*
	Nurse: (acting nurse)	'Yes, and we [the nurse and the patient] have talked, so the patient can just go home now. Goodbye'
	Medical secretary: (acting patient)	'Yes, goodbye…' *Grasps her LEGO® figure and moves the figure out of the examination room (cardboard box) towards the reception on the A0-sized poster (33.1 x 46.8 in). She draws the movement on the poster using the marker.*
What-if discussions	Physician:	'But what if a new patient had arrived [in the meantime]? Then she could just go directly to a free room, right?'

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Table 4. Example of the loop between *what-if discussions*, *pointing*, and *physically testing and interacting*.

From full-scale mock-up simulation PS event 3 This simulation example is related to how cabinets in a depot for bed wards can be placed. The challenge is to obtain the most efficient utilisation of the square metres and at the same time provide the best conditions for work within the depot. The work within the depot is related to handling of stored assistive technologies, e.g. wheelchairs.		
What-if discussions, *Pointing*	Project division staff:	'What if we placed cabinets all the way down in the middle': *Stands within the mock-up and points across the room to indicate where the cabinets could be placed.* 'Then we could walk down one or the other side' *First pointing at one side and then at the other side of the imaginary row of cabinets.*
	Executive nurse 1:	'So, what you are saying is that we can have cabinets here…' *Points across the room in the same direction as the project staff.*
	Executive nurse 2:	'…and then we can open them from both sides?' *Points at each side of the imaginary row of cabinets.*
Physically testing and interacting	Executive nurse 1:	'Yes, that might work. Let's try that.' *Grasps several large foam blocks and places them in the middle of the room to symbolise the row of cabinets.* …
What-if discussions	Executive nurse 3:	'But what if we have to place a wheelchair in here?'

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Table 5. Example of the sequential relationship of *what-if discussions*, *addressing ergonomics consequences*, *pointing,* and *formulating joint design specifications*.

<table>
<tr><td colspan="3">From blueprint simulation PS event 3

The challenge of this simulation is to place an isolation patient in the new ICU. The patient has to be in isolation because of an infection. The aim is to place the patient in a bedroom close to the sluice room, in order to minimise the distance that the waste from the isolated patient has to be transported. When decreasing the distance, the risk of passing the infection on to other patients is decreased, and the amount of walking for the nurses is decreased.</td></tr>
<tr><td>What-if discussions,

Pointing</td><td>Nurse 1:</td><td>‘What if we place him here?’ Points at one of the bedrooms in the blueprint.</td></tr>
<tr><td>Address ergonomics consequences, Pointing</td><td>Coordinating nurse:</td><td>‘Yes, then he is close to the sluice room, to the depot, to all the things.’ Points first at the sluice room and then to the depot on the blueprint.</td></tr>
<tr><td>What-if discussions</td><td>Nurse 2:

Coordinating nurse:</td><td>‘But it depends on which other patients we have at the moment.’

‘Then we could also place him in bedroom number eight?’ (Bedroom Number 8 is at the other side of the building.)</td></tr>
<tr><td>Pointing, Address ergonomics consequences</td><td>Nurse 1:</td><td>‘Yes, he can be placed there or over here…’ Points at the first proposed bedroom and then at Bedroom 8.

‘…because then [in both cases] he is close to the sluice room and the depot.’ Points at the sluice room and the depot.</td></tr>
<tr><td>Formulating joint design specifications</td><td>Nurse 2:

Occupational therapist, Nurse 1:</td><td>‘So we all agree that he has to be placed in that end of the building.’

‘Yes.’</td></tr>
</table>

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Table A1. The coding protocol of the video recordings

Main activities	Description of main activities	Sub-activities	Description of sub-activities
Sharing work experiences	Share work experiences or viewpoints based on professional background.	*Explaining personal needs*	Explaining individual personal needs based on professional work experiences.
		Explaining own work	Explaining own work in the current or future work system.
		Including actors not present	Taking professions or other actors into account who are not related to the participant's profession and not present at the simulation.
		Asking other participants	Asking about other participants' work and work experiences.
Interacting with simulation medium	When the simulation medium is actively applied in discussions among the participants.	*Pointing*	Pointing at the simulation medium, but not physically interacting.
		Physically testing and interacting	Physically interacting with the simulation medium by grasping or moving parts.
Experimenting	Test or discuss different design suggestions or scenarios.	*Acting scenarios*	Acting scenarios either defined beforehand or developed continually during the simulation events.
		What-if discussions	Discussions of future scenarios, often starting with 'what if…'
Reflecting	Consider, assess, and react to the insights on future ergonomics conditions obtained during experiments.	*Addressing ergonomics consequences*	Addressing and assessing ergonomics consequences of the work system design.
		What happened here	Wondering comments, often starting with 'what happened here…?'
		Emotional reactions	Spontaneous emotional reactions related to the realised ergonomics consequences.
Proposing new design	Jointly agree upon design changes of the work system.	*Manipulation of simulation medium*	Introduction of design changes by manipulating the simulation medium.
		Formulating joint design specifications	Jointly formulated design specifications in the form of either specific requirements or intangible focus points.

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Table B1. The sequential relationship between the 13 sub-activities, expressed as frequencies of the identified sequences. The frequencies are normalized in relation to the total number of sequences (4,417) identified between all sub-activities. The direction of the sequential relationships is from the sub-activities listed in the columns to the sub-activities listed in the rows. The grey scale indicates where the highest frequency occurred.

	Simulation starts	Acting scenarios	What-if discussions	Physically testing and interacting	Pointing	Asking other participants	Explaining own work	Explaining personal needs	Including actors not present	Addressing ergonomics consequences	Emotional reactions	What happened here	Formulating joint design specifications	Manipulation of simulation medium	Simulation ends
Simulation starts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acting scenarios	0.07	2.26	0.95	1.34	0.41	0.23	0.77	0.11	0.11	0.57	0.11	0.02	0.16	0.02	0.00
What-if discussions	0.18	1.13	3.74	1.54	2.26	0.52	3.26	0.45	0.93	5.14	0.54	0.11	1.22	0.25	0.00
Physically testing and interacting	0.00	2.42	1.56	3.42	1.38	0.29	1.25	0.14	0.16	1.20	0.18	0.07	0.25	0.16	0.00
Pointing	0.18	0.68	2.72	1.22	2.31	0.29	1.72	0.20	0.45	2.20	0.23	0.07	0.82	0.11	0.00
Asking other participants	0.00	0.50	0.72	0.45	0.34	0.11	0.82	0.20	0.23	0.68	0.16	0.00	0.16	0.00	0.00
Explaining own work	0.00	0.57	2.08	0.68	1.20	1.97	1.15	0.25	0.48	1.74	0.27	0.16	0.41	0.07	0.00
Explaining personal needs	0.00	0.02	0.52	0.02	0.16	0.27	0.29	0.05	0.09	0.25	0.02	0.00	0.07	0.00	0.00
Including actors not present	0.00	0.07	0.70	0.11	0.48	0.14	0.34	0.05	0.14	0.54	0.07	0.11	0.27	0.02	0.00
Addressing ergonomics consequences	0.02	0.70	6.57	1.29	2.51	0.45	1.81	0.36	0.41	1.70	0.43	0.25	0.70	0.14	0.00
Emotional reactions	0.00	0.09	0.72	0.27	0.18	0.07	0.23	0.05	0.09	0.48	0.05	0.05	0.05	0.00	0.00

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What happened here	0.00	0.11	0.18	0.11	0.11	0.02	0.14	0.05	0.02	0.18	0.00	0.02	0.05	0.00	0.00
Formulating joint design specifications	0.00	0.05	0.75	0.14	0.48	0.02	0.41	0.05	0.20	1.36	0.07	0.07	0.23	0.05	0.00
Manipulation of simulation medium	0.00	0.02	0.20	0.07	0.16	0.00	0.02	0.02	0.02	0.23	0.07	0.02	0.02	0.00	0.00
Simulation ends	0.00	0.00	0.09	0.00	0.05	0.00	0.05	0.02	0.02	0.05	0.07	0.00	0.02	0.00	0.00

Table C1. The overlap of timestamps between the 13 sub-activities. The overlaps displayed are normalised in relation to the total number of overlaps (2,288) between all of the sub-activities. The table can be read from the columns to the rows and from the rows to the columns. The grey scale indicates where the highest frequency of overlap occurred.

	Acting scenarios	What-if discussions	Physically testing and interacting	Pointing	Asking other participants	Explaining own work	Explaining personal needs	Including actors not present	Addressing ergonomics consequences	Emotional reaction	What happened here	Formulating joint design specifications	Manipulation of simulation medium
Acting scenarios	0.00	0.13	10.31	1.35	0.70	1.40	0.04	0.09	0.31	0.00	0.00	0.04	0.00
What-if discussions	0.13	0.00	4.20	11.19	0.83	1.97	0.52	0.87	1.09	0.04	0.00	0.26	0.09
Physically testing and interacting	10.31	4.20	0.00	0.04	0.44	0.92	0.09	0.04	0.87	0.04	0.00	0.09	0.74
Pointing	1.35	11.19	0.04	0.00	0.26	0.79	0.22	0.17	4.41	0.13	0.13	0.39	0.00
Asking other participants	0.70	0.83	0.44	0.26	0.00	0.39	0.00	0.00	0.35	0.04	0.13	0.00	0.00
Explaining own work	1.40	1.97	0.92	0.79	0.39	0.00	0.31	0.09	0.92	0.09	0.04	0.04	0.04
Explaining personal needs	0.04	0.52	0.09	0.22	0.00	0.31	0.00	0.00	0.35	0.39	0.00	0.00	0.00

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Including actors not present	0.09	0.87	0.04	0.17	0.00	0.09	0.00	0.00	0.61	0.04	0.00	0.09	0.00
Addressing ergonomics consequences	0.31	1.09	0.87	4.41	0.35	0.92	0.35	0.61	0.00	0.17	0.09	0.35	0.17
Emotional reaction	0.00	0.04	0.04	0.13	0.04	0.09	0.39	0.04	0.17	0.00	0.00	0.00	0.04
What happened here	0.00	0.00	0.00	0.13	0.13	0.04	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Formulating joint design specifications	0.04	0.26	0.09	0.39	0.00	0.04	0.00	0.09	0.35	0.00	0.00	0.00	0.00
Manipulation of simulation medium	0.00	0.09	0.74	0.00	0.00	0.04	0.00	0.00	0.17	0.04	0.00	0.00	0.00

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Figure captions

Figure 1. The table-top model after scenario playing.

Figure 2. The full-scale mock-up of chipboard walls and foam bricks.

Figure 3. Blueprints of the ICU LEGO® figures and bricks applied in the PS events.

Figure 4. The three steps of analysis.

Figure 5. A framework of the knowledge creation process in PS.

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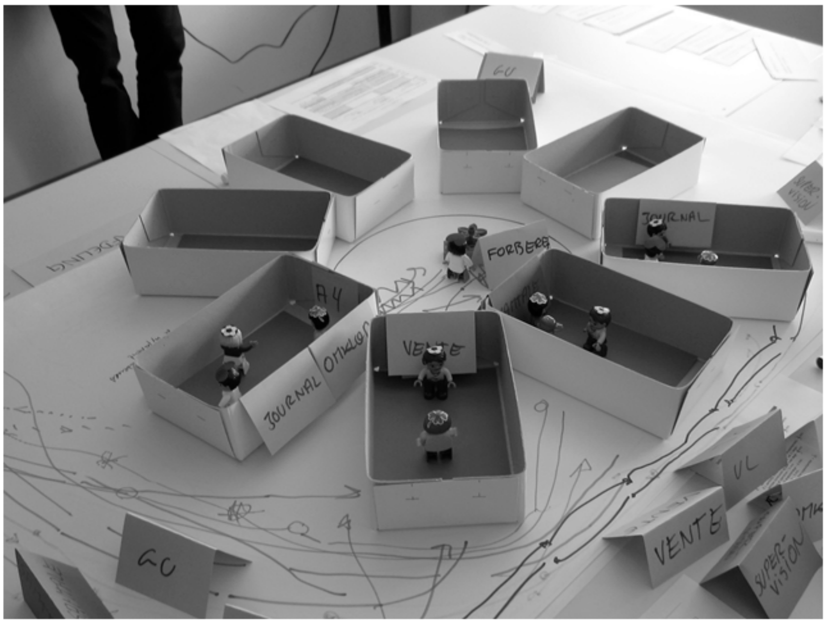

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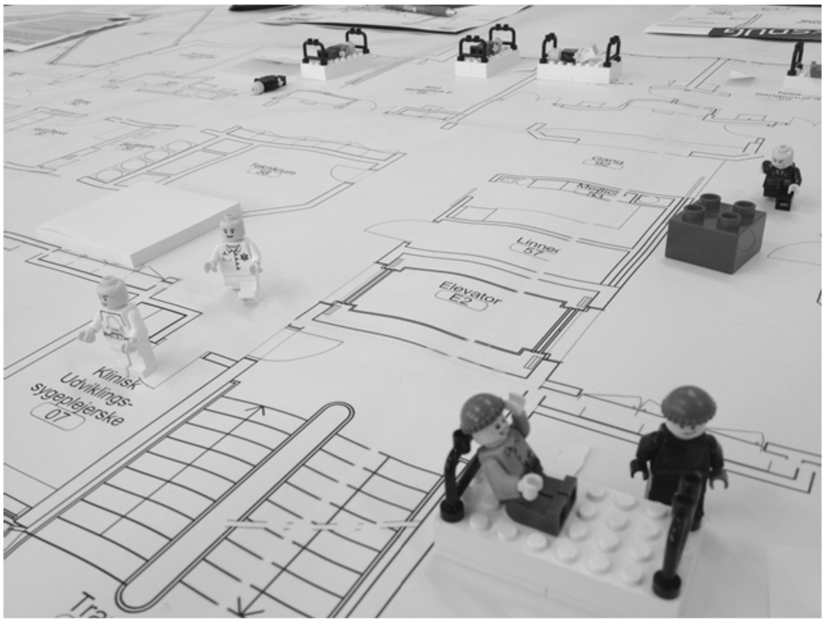

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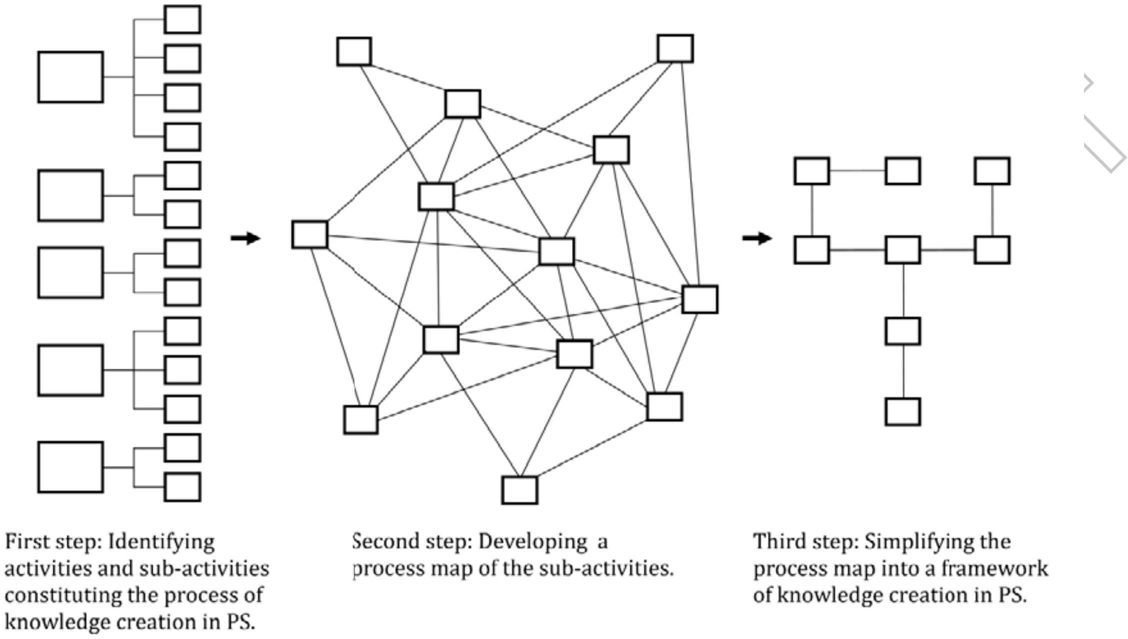

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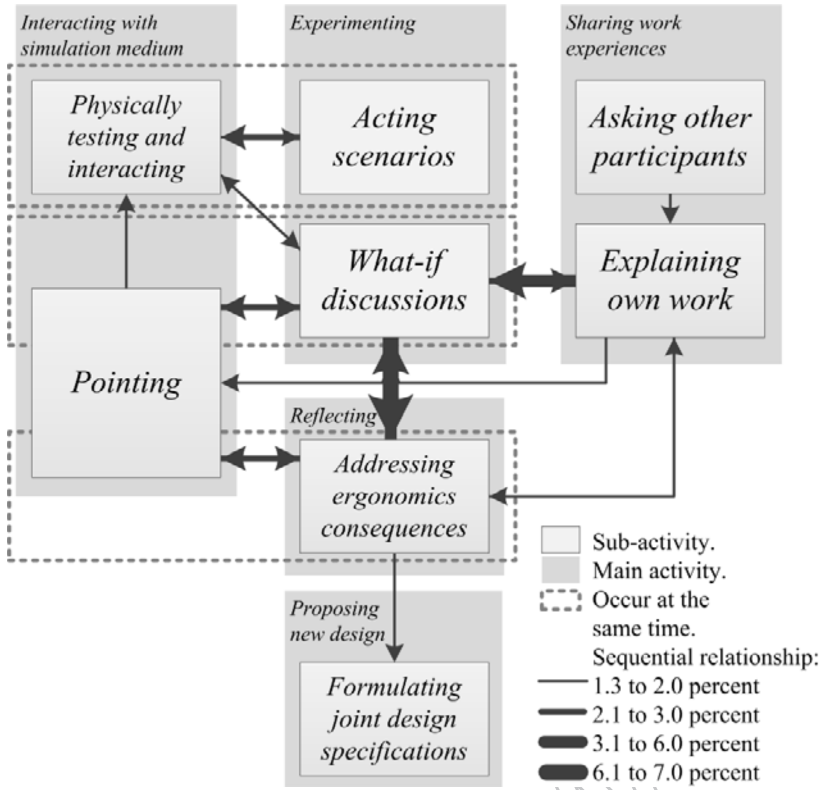

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