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Studying distributed cognition of simulation-based team training with DiCoT

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Abstract: Healthcare organizations employ *simulation-based team training* (SBTT) to improve skill, communication and coordination in a broad range of critical care contexts. Quantitative approaches, such as team performance measurements, are predominantly used to measure SBTTs effectiveness. However, a practical evaluation method that examines how this approach supports cognition and teamwork is missing. We have applied *Distributed Cognition for Teamwork* (DiCoT), a method for analysing cognition and collaboration aspects of work settings, with the purpose of assessing the methodology's usefulness for evaluating SBTTs. In a case study, we observed and analysed four Emergo Train System® simulation exercises where medical professionals trained emergency response routines. The study suggests that DiCoT is an applicable and learnable tool for determining key distributed cognition attributes of SBTTs that are of importance for the simulation validity of training environments. Moreover, we discuss and exemplify how DiCoT supports design of SBTTs with a focus on transfer and validity characteristics.

Keywords: simulation; team training; distributed cognition; prehospital medicine, methodology

50 word Practitioner Summary: In this study, we have evaluated a method to assess simulation-based team training environments from a cognitive ergonomics perspective. Using a case study, we analysed Distributed Cognition for Teamwork (DiCoT) by applying it to the Emergo Train System®. We conclude that DiCoT is useful for SBTT evaluation and simulator (re)design.

1 Introduction

Healthcare organizations worldwide have developed simulation-based team training (SBTT) programmes to improve the knowledge and communication skills of medical professionals (Eppich et al. 2011). Simulation exercises are used to prepare frontline workers for disasters and infrequent events (Legemaate, Burkle Jr., and Bierens 2012; Sundnes and Birnbaum 2003; Bewley and O’Neil 2013). Simulation and training have several advantages: they improve learner commitment, support repetitive practice and provide means of adjusting training difficulty to match learner objectives. Moreover, they can be used as a basis for after-action reviews, which can leverage learning (Okuda and Bryson 2009). Overall, studies suggest that SBTT methods positively impact healthcare team processes and patient safety (Weaver, Dy, and Rosen 2014; Salas, Gregory, and King 2011; Daniels and Auguste 2013).

However, the greater part of evaluation studies performed in medical settings on SBTT effectiveness and team performance is quantitative and outcome-based. A general difficulty with such black-box approaches is that they do not identify how the simulation setup affects and shapes teamwork training. This is a concern, as numerous studies have found that clinical decision-making and collaborative performance are heavily dependent on the actual physical setups and arrangements of a work setting (Hutchins and Lintern 1995; Bang and Timpka 2003). Interestingly, these workplace studies point to a set of teamwork coordination issues that must be considered when evaluating and designing training environments, since the trained behaviours are later enacted in the workplace setting. This issue is related to the validity of the simulation and how well knowledge is transferred and used in the actual work setting. However, these questions are infrequently examined from a cognitive ergonomics perspective. The underlying hypothesis in this study is that the perspective of Distributed Cognition (DCog; Hutchins & Lintern, 1995) is both applicable and valuable in the simulation context. DCog can be used to clarify the roles of physical tools and

artefacts of SBTTs and elucidate their relationship to the actual workplace, providing a better understanding of simulation validity and knowledge transfer. Another benefit of such an analysis of the simulation setting is that it can be used to inform (re)design of simulators.

In this paper, we report on the use of a workplace study approach, Distributed Cognition for Teamwork (DiCoT; Furniss and Blandford, 2006), as a method for studying validity of SBTT systems using a case study approach. The case study is made up of four training sessions where multi-professional clinical teams used the Emergo Train System (ETS) SBTT for training prehospital and emergency medicine management. Such simulation and training domains have not previously been studied using DiCoT. Our general focus is on how the simulator environment supports teamwork mechanisms and what roles cognitive artefacts and tools play in shaping the teamwork. The goal of this case study is twofold: (1) to assess the applicability of DiCoT for studying aspects of teamwork and simulation validity in SBTT simulations; (2) to explore DiCoT as a basis for (re)designing SBTT simulators. In doing so, our work follows previous methodology research by John and Packer (1995) and Berndt and colleagues (2014).

The paper is organised as follows. First, we discuss core theoretical concepts in simulation and in DCog. Moreover, we review SBTT evaluation studies. Second, we present the methodological setup and provide a DiCoT analysis of the four training cases. Based on the analysis, we discuss the applicability of DiCoT as a method for evaluating SBTTs and for informing the design of such training environments.

2 Background

2.1 Training simulations

According to Feinstein and Cannon (2002), three theoretical constructs are important to consider when evaluating any simulation of reality: *fidelity*, *verification* and *validation*. In

simulation-based training, fidelity represents the *level of realism* that is presented to the trainee (Singer and Hayes, 1989). Verification has to do with how well the simulation is constructed; hence, the term is used when evaluating technically complex simulators. Validity is seen as a measure of *what* is simulated in terms of replicating *factual things*, such as real world objects and processes, which are called *simulands* (Sokolowski & Banks, 2010). Simulation validity is regarded as a very important property of a medical simulation (Bewley and O'Neil 2013). Validity is a multifaceted topic, which Feinstein and Cannon (2002) systematized in two categories; (1) *representation* and *application* validity and (2) *internal* and *external* validity. The first category concerns how the simulands are represented (representation validity) and whether the simulation achieves its intended effects on trainees (application validity). The second category is related to how well the simulation actually reflects the simulands (internal validity) and the degree to which behaviour in the simulation is similar and applicable to a real situation (external validity).

Another important trait of any simulation environment, as discussed by Bewley and O'Neil (2013), is *reliability*, which is defined as the measurement consistency (test-retest stability). According to Sokolowski and Banks (2010) there are numerous methods for evaluating simulations with regard to validity: informal methods that rely on subjective assessment of the model and the simulation results based on expertise (face validation, etc.); formal methods, which employ mathematical proof of correctness; and static methods (hypothesis testing, output data analysis, etc.) that assess model accuracy and the output of the simulation – i.e., the effect of the simulation. The DiCoT methodology would be categorized as an informal evaluation method. As this study is concerned with teamwork validity aspects, we will in the next section discuss how researchers have studied teamwork in the workplace.

2.2 *Evaluation in the Real World: Workplace Studies*

Researchers have come to understand that cooperating actors actively perform many actions to facilitate face-to-face teamwork. Naturally, gesture and gaze are part of the joint communication system, but teams also tacitly monitor each other and perform routine actions to support understanding of situations among colleagues (Schmidt and Simonee 1996). The physical setup of the workplace is important in this regard as it can hinder or support collaboration. Interestingly, professionals commonly set up the workplace to create coordination mechanisms (ibid.) and *cognitive artefacts* (Norman 1993) that both aid team communication and support memory and attention.

Distributed cognition (DCog) is a sociotechnical framework that emphasizes how such workplace arrangements facilitate collaboration and cognition; DCog further claims that cognitive processes are distributed over multiple artefacts and actors, allowing the researcher to ‘step inside’ the cognitive system and observe it (Hutchins and Lintern 1995). Typically, with DCog, one can thus identify how artefacts support teamwork and offload cognitively demanding tasks. The perspective illuminates not only the structure of a sociotechnical system but also the representation and transformation of information in work processes. Typically, studies include analyses of tools and spatial arrangement of artefacts and how they are employed to coordinate cognition and teamwork (Kirsh 1995; Perry 2003). Clinical cognition and collaboration have been studied extensively using DCog (Hutchins and Lintern 1995; Klein and Calderwood 1991; Bang and Timpka 2007). These studies suggest that clinical work environments are organized in ways that offload cognitively demanding tasks and support teamwork collaboration, giving credence to the claim that the environment shapes collaboration. In the next section, we highlight common evaluation approaches used in SBTT research.

2.3 *Evaluating SBTT Environments*

We believe it is feasible to consider teamwork processes and mechanisms as one aspect of internal validity of SBTTs – i.e., whether the correct teamwork properties are correctly implemented. This aspect of validity is sometimes referred to as psychological fidelity (Maran & Glavin, 2003) or cognitive fidelity (Hochmitz & Yuviler-Gavish, 2011). However, studies of SBTT environments often focus on the performance of participants (the output) and are less concerned with *how* cognitive and collaborative properties are manifested (Weaver, Dy, and Rosen 2014). For instance, the Kirkpatrick model is an example of a quantitative framework for evaluating training and educational settings (Kirkpatrick 2005, in Bewley and O’Neil 2013). Based on a set of measured variables, the approach is used to identify and quantify positive behavioural changes and performance benefits for an organization. Expert performance methods are related to the Kirkpatrick model in terms of their focus on simulation outputs. In these approaches, trainee performance is compared to expert performance or evaluated by experts that grade trainee performance (Bewley and O’Neil 2013).

Qualitative approaches to evaluation are used in the SBTT context. Power et al (2013) applied an informal evaluation method to appraise acceptability, relevance and applicability of high-fidelity emergency medicine simulations with technically advanced patient dolls. This method investigates *participant experiences* of using the simulation, which is assessed post-simulation through stimulated response sessions (using video playback) and questionnaires. In a similar study, Overly, Sudikoff and Shapiro (2007) observed paediatric residents working in a high-fidelity medical simulator to assess their ability to manage an acute airway. With this method, they were able to identify several areas of trainee performance. Domain modelling is another informal approach to evaluation that attempts to model the cognitive demands of a domain. The model specifies how various task performance variables, such as hypothesized

knowledge and skills, relate to task outcomes using Bayesian networks (Bewley and O’Neil 2013).

2.4 *DiCoT*

There are few methods that operationalize theoretical concepts from DCog (Cohen et al. 2006; Furniss and Blandford 2006; Halverson 2002; Sellberg and Lindblom 2014). DiCoT is a notable exception in its approach to making DCog studies more concrete by applying a step-by-step procedure with the goal of understanding cognitive work and informing system (re)design (Furniss and Blandford 2006). DiCoT is primarily intended for analysing small teams based on central ideas in the DCog literature, such as how artefacts in the environment support or hinder group work; mostly, it has been used to study cognitive processes in health care settings (c.f., Berndt et al., 2014; Furniss et al., 2015; Werth and Furniss, 2012).

Ethnographical field studies are commonly employed to gather data, which allows the researcher to observe and document DCog processes in their natural work setting. Typically, ethnographical studies involve participatory and passive observation techniques together with situated interviews with frontline workers. The observer-participant relationship is similar to a master-student relationship (Agar 2008; Beyer & Holtzblatt, 1998), which allow researchers to query participants about key tasks and goals during the teamwork.

DiCoT breaks a DCog analysis down into five models, of which the first three were applied in this study. Each model consists of a set of principles, see Table 1. The *physical layout* model (Principles 1-7) describes how the physical structure of a workplace supports or hinders collaboration. The *information flow* model (Principles 8-14) describes movement of information within the system. The *artefacts and environment* model (Principles 15-18) describes how artefacts are used to coordinate and mediate cognitive work. Beyond these three core models, DiCoT also provides models for analysing social structures and system

evolution. These models were not used in the present study but are described elsewhere (Furniss & Blandford, 2006). Table 1 shows each principle employed in this study, as described by Furniss and Blandford (2006).

[Table 1: The Principles of DiCoT. Adopted from Furniss and Blandford (2006).]

3 Emergo Train System

This study analyses the Emergo Train System® (ETS), which is a low-fidelity simulation tool used for training medical professionals in emergency and disaster management. ETS has been used to train people in major civil incident doctrines¹, preparedness, triage, patient management, command and control, coordination/liaisons and medical surge capacity (Heléne Nilsson et al. 2013; Heléne Nilsson, Vikström, and Rüter 2010; Rådestad et al. 2012). ETS is used to train and to evaluate different aspect of emergency medicine such as response and surge capacity. The goal for participants in a simulation session – which can include doctors, nurses, prehospital personnel, and external actors – is, as in real life, to reduce preventable patient deaths and complications. ETS simulates medical logistics in terms of the movement of patients from the accident site to hospital admission and subsequently to specialist departments. Participants in a simulation are asked to identify and prioritize (triage) victims, administer emergency treatments, and transport patients to receiving hospitals. Several instructors are assigned with managing the simulation, which involve: simulation setup, assisting participants, monitoring timers, role-playing external actors, and taking notes for evaluation and after-action review.

¹ It is, for example, used in the Swedish national concept for prehospital medical command and control at major incidents; visit www.psconcept.se for more information.

A scenario in ETS is represented on a set of whiteboards using an elaborate set of victim and resource magnet symbols (see Figure 3). Typically, one or more whiteboards represent the accident site, and this is where the prehospital teams prioritize patients and make lifesaving decisions. Additional whiteboards often represent the emergency departments and intensive care units at various hospitals. Fundamental to ETS is a victim bank with over 500 victim figures that all have projected outcome measures—preventable death and preventable complications. The patient bank was developed in a consensus process by Swedish experts in traumatology and disaster medicine in accordance with evidence-based best practice. The approach also includes time required for each medical intervention (applying treatment, transport, etc.).

4 Study Method

Ethnographical field study methods (Hughes et al. 1994) were used during four typical ETS simulations at a centre for teaching disaster medicine in Sweden. Data were collected primarily through participatory and passive observation techniques in combination with interviews with exercise participants and instructors. The researchers were initially open in their data gathering strategy, but narrowed down the focus to participant and instructor interactions with and by the whiteboards – a process that was guided by the previous observations. Observations were mainly made from a strategic position with a good overview of the whiteboard representing the accident site, where most of the simulator interaction took place. Situated interviews were generally conducted with the participants and instructors after they had completed the simulations, but clarifying questions were also asked during the simulations. Interviews were open, focusing on how and why decisions and interactions were made by participants and instructors during the simulation. In one of the four simulations (E4) the researcher also helped to manage the simulation by moving and sorting ETS figures.

Below, the observed simulation exercises are described:

- E1: Prehospital Refresher Course. This exercise was a follow-up that targeted ambulance personnel who had previously completed a basic course in command and control. The exercise was training-oriented (formative) using a minor scenario that comprised five participants, one instructor, and it lasted for about one hour.
- E2: ETS Instructor Training. This was a training simulation for future instructors in prehospital medical command and control training. The session included two groups of eight participants and three instructors. The groups alternated between training in two simulated scenarios, each lasting about two hours including discussion session.
- E3: Surge Capacity Simulation 1. In contrast to E1 and E2, the purpose of this exercise was to evaluate (not train) response preparedness and medical capacity. The scenario was a school shooting in which participants from regional hospitals, regional management, emergency dispatch services and ambulance services were included. The simulation was a full-day activity, managed by several instructors, which involved over 20 participants.
- E4: Surge Capacity Simulation 2. A second evaluation exercise, similar in size and setup to E3, in which the scenario was a fire at an institution for treating prisoners. Beyond the participating organisations in E3, this simulation also included personnel from the forensic psychology treatment institution.

The resulting data from the simulations were primarily personal notes, interview transcripts, and photographs, which were analysed as a single descriptive case study (Yin 2003). Data were stored, coded, and filtered using Microsoft Excel worksheets. The worksheets were analysed iteratively using the DiCoT principles and models as top-down

codes. Snippets of data were often assigned several overlapping codes. During coding, the two additional DiCoT models were not applied as the data did not fully support this.

5 A DiCoT Analysis of ETS

In this section, we present the resulting DiCoT analysis of ETS based on three DiCoT models: physical layout, information flow, and artefacts and environment. We will use parentheses to refer to specific DiCoT principles in the analysis; (P.1) will refer to Principle 1, (P.2) Principle 2, etc. (see Table 1). Even though the models are presented as separate sections, it should be noted that they frequently overlap and are difficult to distinguish at times.

5.1 Model 1: Physical Layout

The physical layout model describes the spatial distribution and arrangement of tools and agents. Broadly, ETS simulations consist of participants and instructors and the artefacts used to create a scenario. The number of instructors needed to simulate an exercise in ETS depends on the size and purpose of the training. In E1, a single instructor managed the entire exercise. In the larger E3 and E4 exercises, the number of instructors varied between six and eight. Participants in the simulation are mostly emergency medicine professionals that train or are being evaluated. The number of participants ranged from five in E1 to over 20 in E3 and E4.

5.1.1 Core of the Simulation

Between exercises E1 – E4, the physical arrangement varied due to the size and purpose of each exercise. In the two surge capacity evaluations, E3 and E4, 14 whiteboards were used, and in exercise E1 only one whiteboard was employed (p.7). Figure 1 shows the layout of exercises E3 and E4 and Figure 2 shows the smaller E1.

[Figure 1: Spatial layout of exercise E3 and E4. The thin rectangles represent whiteboards, while the rounded squares represent tables.]

[Figure 2: Spatial layout of exercise E1.]

Accident sites in ETS were represented on whiteboards by means of drawings and printed photos (P2, P3). Parts of an accident site could be covered to indicate inaccessible or unexplored areas; this was a method to reduce a participant's horizon of observation (P.6). Instructors could later grant access to covered parts of the accident site once, for example, a fire had been put out. Figure 3 shows a section of the accident site from exercise E3.

[Figure 3: A partially covered accident site. A large paper sheet is used to hide a sector of the accident site, preventing participants from accessing part of the patient group.]

Magnetic figures represented patients, transport and resources on the whiteboards (P.3). These figures provided a supportive cognitive structure for both participants and instructors throughout the exercise. Participants performed triage and treatment of patients by attaching adhesive labels on them; see Figure 4.

[Figure 4: Patient treatment and triage. Adhesive labels represent treatments and triage of the patient.]

Participants often placed figures together to group patients (by triage colouring or destination) as a form of cognitive scaffold to provided cues for situation awareness (P.1, P.5, 16). There were no explicit representations of resource allocation on the whiteboards, but one frequently employed method was to spatially group a patient with the resources required for treatment or transport (P1, P2, P3). However, how the participants' allocated resources varied from person to person and between exercises, as nothing prevented participants from treating a patient without the required resources (such as available ambulance personnel, etc.).

In real life, actions such as response, treatment, examination, triage and transport take time and resources to perform. However, in an ETS simulation, these actions are immediate. Keeping track of treatment periods was up to the participants themselves; transport was timed by the instructors. To do the former, participants must note treatment start time, look up

treatment duration (using a treatment schedule) and estimate the finishing time. A frequently used cognitive scaffold was to write down the finishing time next to the patient figure as an external memory aid (P.15, 16).

5.1.2 Exercise Awareness

Maintaining an overview and an awareness of the state of the exercise were key tasks for instructors (P5, P6). Maintaining instructor situation awareness was related to the openness (Garbis 2002) of artefacts and to the flexibility of the whiteboards (P1, P2, P5, P6). The whiteboards provided an open and accessible representation of the state of the exercise, such as the number of triaged patients, patients still located at the accident site, and transport (P5, P6, P17). The straightforward representation facilitated estimation of exercise progress and participant performance. In some exercises, a specific whiteboard representing ongoing transport was employed by instructors to maintain a view of en route ambulances' destinations and their arrival times.

Instructor actions can be seen as triggers for participants (P6, P14). In the same way, participants who interact with patient figures generate body language (pointing, reaching, etc.: P4) that indicate to the instructors that work is going on (P.6), which helps maintain instructors' awareness (P5, P6). The physical placement of the whiteboards, in exercises E3 and E4, required instructors to walk across the room to move patients from the transport whiteboard to the hospital whiteboards. This activity could notify the participants that something was about to happen at 'their' whiteboard (P4, P5, P6). This practice was troublesome for the instructors when, for instance, they needed to remember transport arrival times while moving several figures.

5.2 Model 2: Flow of Information

This part of the analysis investigates the flow and propagation of information in ETS

simulations. Figure 5 shows a diagrammatic representation of the general information structure between participant roles during a simulation, illustrating both the prehospital medical command structure and general simulation whiteboard setup.

[Figure 5: Prehospital command structure and information movement. The dashed figures indicate roles typically enacted by an instructor. Squares represent typical whiteboards (wb) used.]

[Table 2: Description of communication paths. The roman numerals correspond to the path boxes in Figure 1.]

5.2.1 Participant and Instructor Communication

Face-to-face and radio-based team communication was essential in the observed ETS simulations (P8, P12). At an accident site, paramedics arrived in teams of two, which were briefed face-to-face by the Ambulance Incident Commander (AIC) and the Medical Incident Commander (MIC) on the situation. In ETS, the participants are called in from another room via radio when it is time for their ‘ambulance to arrive’. As can be seen in Figure 5, the AIC has a central role in coordinating the flow of information (P8), particularly between the accident site and back-end regional management. Moreover, digital report systems are not used in ETS; instead the AIC fills out report sheets on paper and communicates this information via radio to the designated duty officer (DDO) (P12). Instructors frequently took an active role in the scenario by enacting other professions and roles not being trained, for instance rescue commander (RC) or emergency dispatch commander (EDC). Instructors either spent the entire simulation enacting a role or alternated between role-playing and exercise management. Moreover, participants could sometimes overhear instructor-instructor discussions giving them access to information not available in the horizon of observation during a real prehospital response situation (P6, P8).

5.2.2 Transforming and Moving Information

Participants frequently used the whiteboards to make information public, intentionally or

unintentionally, expanding the horizon of observation of other participants and instructors (P6). By grouping and highlighting patient figures with a marker, participants moved and transformed information from internal representations to open and external representations, which contributes to shared situation awareness (P5, P6, P8, P9). Participant transformations of the shared representations were observed during the propagation of patient referrals (decision on receiving hospital). This process was initiated as a verbal message via a radio link (see Figure 5, path II). Once the information was received by the AIC, it was immediately written down as text in a notepad and shared verbally with a colleague, and finally the information was ‘publicised’ on the whiteboard (P6, P8, P9, P16). Another example of information transformation was patient listing: when counting patients, one participant drew a line on the whiteboard for each patient counted. This approach aided the counting process, but it also transformed the extrinsic property of ‘patient count’ into a visually computable representation, thus, changing the task from mental arithmetic to visual perception (see Figure 6; P9, P16, P2).

[Figure 6: Patient count. A cognitive scaffold that transforms a mental task into a perceptual task.]

5.2.3 Immersion Triggers

In ETS, there are artefacts and representations such as maps and accident site photos that trigger immersion to trigger previous experience (P3, P14, P15). According to the instructors, they showed pictures and maps during the simulation as a way to help participants reflect, visualize the accident, and trigger previous experiences (see Figure 7).

[Figure 7: Accident site maps. Maps displayed on the accident whiteboard to trigger scenario immersion.]

5.3 Model 3: Artefacts and Environment

This DiCoT model describes how artefacts are designed and used to support cognition. In the

analysis, we have already seen examples of artefact techniques that transform information, provide computational offloading, and trigger immersion. Model 3 looks closer at instructor artefacts and flexibility of representations.

5.3.1 Managing a Simulated Scenario

In this section, we examine exercise management before, during, and after a simulation.

Instructors made a lot of arrangements (pre-computation) before a simulation, for instance by arranging patient figures in various piles (P1) and by rehearsing the scenario scripts. One instructor made sure that all material for the upcoming scenario was close at hand simply by placing it in his trouser pockets. This strategy can be seen as scaffolding (P16) consisting of both bodily support (P4) and intelligent use of space (Kirsh 1995; P1). During the simulation, instructors used a script-artefact—a paper script listing all events in the scenario—as external memory to run the exercise (P15). The script showed temporal information (in minutes) of when events in the scenario would take place (e.g., ‘+2 min: the second ambulance arrives’). This information, however, did not aid instructors in keeping track of the current time. Instead, the instructors sometimes used a smartphone app or a wall clock (also observable by the participants) to control the temporal aspects of the exercise, such as initiating events, timing transports, and evaluating participant performance (using quality indicators, see H Nilsson and Rüter 2008). A related task for the instructor was to adjust the challenge and tempo of the exercise in accordance with participant performance (P5, P6). If participants were struggling with the scenario, instructors could delay upcoming events in the simulation (during training exercises). Instructors could also increase task complexity by adding patients and accelerating events. Timing all transport periods and scenario events was seen as the most demanding task for an instructor. This required a strategic spatial position (P5, P6) with an overview of the exercise. The times were recorded on the whiteboard or a laptop.

A general goal for prehospital care is to treat and transport all patients in need of medical assistance in time. To evaluate the exercise outcome in an after-action review, instructors relied on the final state of the representations, such as the whiteboards, the logs they kept and adhesive labels on patients. For example, untreated patients or patients left at the accident site would indicate that participants did not reach a preferred goal state. Hence, instructors could perform a visual evaluation of participant performance due to the openness of ETS artefacts (P2, P5, P6, P17). However, to avoid preventable complications or deaths, some treatments needed to be administered within a given timeframe, meaning that instructors had to record when treatments were administered to know if complications had occurred or not.

5.3.2 Flexibility of Representations

Real-life emergency response is dynamic and events are difficult to predict. Therefore, response requires the ability to adapt. However, ETS representations are static. For instance, patient states remained the same throughout a simulation and the accident site was generally unchanged. On the other hand, the static and open nature of the simulation made it easy for instructors to introduce new locations (whiteboards), resources (figures) or visualising processes (transport, etc.) ‘on the fly’ during a simulation (P15, P16). On occasion, participants asked for resources that did not have a representation in ETS, such as a specific vehicle with no magnetic symbol. In these cases, instructors verbally acknowledged that the requested resource had arrived without placing any figures on the whiteboard. This allowed participants to act as if the resources were present, hence triggering new actions and behaviours (P14). Because there is no representation of this resource, instructors must rely on their memory and external notes to include its use during evaluation. However, such flexibility enabled a degree of improvisation in the simulations - an important property in real-world accident management (Franco, Zumel, and Holman 2009). As seen, the flexibility

of ETS grants participants and instructors ample opportunities to create cognitive scaffolding (P16). Figure grouping was a frequently used scaffolding approach to organize tasks and indirectly communicate the accident state to team members.

5.4 Model Summary

In Table 3, we have summarized essential contents of each model and connected them to relevant aspects of simulation validity.

[Table 3: Summary of the results from Section 5 tied to aspects of simulation validity.]

6 Discussion

6.1 Evaluating SBTT Environments with DiCoT

This study suggests that DiCoT can be used to understand important cognitive and collaborative mechanisms related to the validity and design of SBTT environments. Further, in doing so the study demonstrates learnability and applicability of DiCoT. Applying DiCoT to study SBTT environments is relatively straightforward as it provides concrete models and methods to study how the physical setup supports or hampers cognition and collaboration. For example, our analysis identified the importance of flexible interaction with the simulands that allowed participants to generate cues and cognitive scaffolds to structure tasks and coordinate teamwork. This flexibility also supported instructors, as they used the spatial features of the simulation and its artefacts to support situation awareness. The study also revealed that the physical layout and open artefacts of ETS enabled unintended information movements, which allowed participants to acquire unrealistic situation awareness that might affect performance and patient outcome. This problem can be considered a ‘threat’ to simulation validity (Bewley and O’Neil 2013), which further points to a weakness of outcome-based evaluation approaches as they does not identify such sources of error (c.f., Section 6.2).

Some aspects are missing from DiCoT that are needed to better account for the properties of training simulations. For instance, DiCoT does not distinguish between formative and normative modes of simulation (training versus performance evaluation), which would be a valuable extension of DiCoT for use in training contexts. Furthermore, the DiCoT principles are biased towards investigation of temporally and geographically co-located teamwork. This preference makes DiCoT difficult to employ for analysing temporally and physically distributed simulation sessions, such as full-scale emergency simulations using live actors. Another difficulty of DiCoT, and DCoG methodologies in general, is that it produces large amounts of data due to the multifaceted nature of DCoG – especially in combination with analysing an entire simulation system. One solution to this problem is to limit the scope of the study and apply a subset of the DiCoT principles, alternatively, to analyse a subset of the functions of a simulation.

6.2 Redesigning SBTT Environments with DiCoT

A general goal of a DiCoT analysis is to provide input for changing work practices and designing IT support. Based on the DiCoT analysis of ETS, we compiled a list of benefits and drawbacks of implementing a digital version of ETS (see Table 4).

[Table 4: Digital redesign of ETS. The left column indicates benefit, loss or both; the right column describes the property affected.]

As seen in Table 4, the study suggests that digitization of ETS could provide increased internal validity of the simulation. Part of the design challenge is, however, to retain application and external validity. Based on the DiCoT analysis, it seems clear that the open layout and flexible walk-up-and-use interaction style are important and valuable traits for the application validity of ETS, supporting cognition and collaboration as well as making the simulator understandable and easy to use. Further, participants bring their own strategies for managing hard-to-predict situations in emergency medicine. Thus, for a simulation to be

externally valid, it must not constrain the ability of participants to improvise and to make ‘off-the-cuff’ decisions. A high degree of flexibility in terms of user interaction and scenario adaption would contribute to maintaining the high application validity in a digital version of ETS.

However, a problem with ETS is to control the many variables in the simulation, which is partly caused by its high flexibility. Uncontrolled participant interaction may skew simulation performance and the outcome measurements. Interaction flexibility versus simulation control seems to be a balancing act: more control of the simulation variables provides comparable and reliable results but may impede the flexibility and usability of the simulation. This problem can be formulated as an issue of application validity (pedagogics) versus external validity, fidelity (realism), and to some extent internal validity. For example, the openness of the simulation tools and idle treatment waiting times in ETS give participants additional time to explore their horizon of observation—potentially acquiring unrealistic awareness of the situation. In formative training simulations, such ‘bonus’ awareness may be positive as participants will get an opportunity to observe and reflect on their own actions in context. However, if the purpose of the simulation is to challenge and evaluate team performance, unrealistic situation awareness will become problematic, as situation awareness affects performance (Endsley 2000).

As suggested in Table 4, a digital medium can enforce new types of preconditions for actions without changing the representational validity or fidelity of the simulation. For instance, rules can ensure that a patient cannot be moved while undergoing treatment. Increased control of the simulation processes would likely increase the reliability of the performance and the outcome of the simulation. Furthermore, a digital version of ETS could provide new types of content, such as dynamic patient health states based on predefined injury

trajectories. Dynamic patient states would increase aspects of internal and external validity in an SBTT.

7 Conclusion

In this study, we have explored the workplace-based analysis method DiCoT as a means of qualitatively evaluating SBTT environments. The study comprised observation and analysis of a set of training and evaluation sessions where medical professionals used the Emergo Train System SBTT. The results indicate that DiCoT is a promising tool for evaluating simulation and training environments such as SBTTs. The study further tested and demonstrated learnability and applicability of DiCoT within the, for DiCoT, novel simulation context. The primary advantage of this approach is its ability to identify and classify how simulation environments support cognition and teamwork during a training session. The study also indicates that DiCoT is valuable for understanding dimensions of simulation validity in terms of training environment–workplace mappings. Moreover, the aspects that DiCoT can identify may be used as a basis for development and redesign of SBTT environments. In our study, we were able to identify benefits and drawbacks of digitizing ETS based on the analysis. For the future it would be interesting to combine the qualitative approach of DiCoT with quantitative outcome-based measures to evaluate SBTTs from a combined cognitive ergonomics and performance viewpoint.

8 References

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9 Tables

[Table 1: Principles of DiCoT. Adopted from Furniss and Blandford (2006).]

<i>The Principles of DiCoT²</i>	
<i>1. Space and Cognition</i>	The role of space in supporting cognition for supporting choice and problem solving. For example, Furniss and Blandford found that ambulance controllers lay information out on their desks in ways that support their planning.
<i>2. Perceptual Principle</i>	Spatial representations provide more support for cognition than non-spatial ones, provided that there is a clear mapping between the spatial layout of the representation and that which it represents. An example from the ambulance dispatch domain is that calls are displayed on the allocator's screen in order of priority.
<i>3. Naturalness Principle</i>	Similarly, cognition is aided when the form of the representation matches the properties of what it represents; in these cases, what is experienced is closer to the actual thing, so the necessary mental transformations for making use of the representation are reduced. This is referred to elsewhere as 'stimulus-response compatibility'.
<i>4. Subtle Bodily Supports</i>	In interacting with the environment, an individual may use their body to support their cognitive processes; for example, pointing at a place in a book while responding to an interruption is part of the mechanism of remembering where we are.
<i>5. Situation Awareness</i>	One of the key aspects of shared tasks is that people need to be kept informed of what is going on, what has happened and what is being planned. The quality of this situation awareness can be influenced by how accessible the work of the team is. This can also be influenced by the proximity of the person, involving both observation and overhearing a conversation.
<i>6. Horizon of Observation</i>	The horizon of observation is what can be seen or heard by a person. For each person in an environment, this depends on their physical location, the activities they are close to, what they can see, and the manner in which activities take place. The horizon of observation of a person plays a large role in influencing their situation awareness.
<i>7. Arrangement of Equipment</i>	From a DC perspective, the physical layout of equipment affects access to information and hence the possibilities for computation. This applies to the different levels of access to people, their conversations and their work, as well as to physical representations and artefacts. For example, in each team, the allocator and radio operator share access to certain items.
<i>8. Information Movement</i>	Information moves around the system. This can be achieved in a number of different ways which have different functional consequences for information processing. These ways differ in their representation and their physical realisation. Different mechanisms include passing physical artefacts, text, graphic representation, verbal, facial expressions, telephone, e-mail and alarms. Even inaction might communicate information.
<i>9. Information Transformation</i>	Information can be represented in different forms; transformations occur when the representation of information changes. This can happen through artefacts and communication between people. Appropriate representations support reasoning and problem solving. One important transformation is filtering, in which information is gathered, sifted and structured. In ambulance dispatches, filtering is a central activity of call takers, who solicit and structure information from callers for retransmission to the relevant sector desk.
<i>10. Information Hubs</i>	Information hubs can be considered as a central focus where various information channels meet and where various information sources are processed together – e.g. where decisions are made on

² Principle 18: Resource Model, was not used in this study and thus omitted from the table.

various sources of information. Busy information hubs can be accompanied by buffers that control the information to the hub to keep it working effectively.

<i>11. Buffering</i>	As information propagates through a system, there may be times when the arrival of new information interferes with important ongoing activity. Buffering allows the new information to be held up until the appropriate time for it to be introduced. In the case of ambulance control, radio operators frequently buffer information for their sector allocators.
<i>12. Communication Bandwidth</i>	Face-to-face communication typically imparts more information than that conducted by other means, including computer mediated communication, radio and telephone. This richness needs to be recognised when technologies are redesigned.
<i>13. Informal Communication</i>	Informal communication can play an important functional role in the system, including the propagation of important information about the state of the system and the transfer of knowledge through stories, which can have important consequences for learning how the system behaves.
<i>14. Behavioural Trigger Factors</i>	It is possible for a group of individuals to operate without an overall plan, as each member needs to know only what to do in response to certain local factors. These can be dubbed ‘trigger factors’ because of their property of triggering behaviour.
<i>15. Mediating Artefacts</i>	To support activities, people make use of ‘mediating artefacts’. Mediating artefacts include any artefacts that are brought into coordination in the completion of the task. In ambulance control, the ‘tickets’ that contain information about incidents are essential mediating artefacts that are passed around between team members and annotated to keep track of the state of the incident.
<i>16. Creating Scaffolding</i>	People constantly use their environment by creating “external scaffolding to simplify their cognitive tasks”. For example, people may create reminders of where they are in a task.
<i>17. Representation Goal Parity</i>	One way that external artefacts can aid cognition is by providing an explicit representation of the relationship between the current state and a goal state. The closer the representation is to the cognitive need or goal of the user, the more powerful the representation will be. In the case of ambulance control, the allocator’s goal is often to obtain a clear screen—one with no outstanding jobs.

[Table 2: Description of communication paths. The roman numerals correspond to the path-boxes in Figure 1.]

<i>ID</i>	<i>Information Movement Description</i>
I	Phone and “computer” communication between dispatch and DDO. This is seldom included in ETS exercises.
II	Radio and computer report communication between DDO and AIC onsite. AIC provides situation reports and an initial METHANE report, DDO provides AIC with patient referrals (distribution to receiving hospitals). In ETS, radio and report sheets are used. In ‘real life’, a computer system is also used.
III	DDO assesses hospital capacity over the phone. This is seldom included in ETS exercises.
IV	Radio communication between EDC and another organization’s onsite management. Not the focus (and seldom part) of the ETS exercises.
V	EMC and AIC radio communication. Distributing preliminary alarm information on route to the accident site. EDC also receive situation reports. Central to the initial phase of ETS exercises.
VI	AIC situation reports are distributed to the emergency departments of regional hospitals. This is seldom included in ETS exercises.
VII	On-site, face-to-face or radio communication between other first responding agencies. Instructors often act as the other agencies as necessary.
VIII	On-site, face-to-face and radio communication between AIC and MIC. Central to ETS exercises.
IX	Face-to-face and radio communication onsite: coordinating response, helping AIC to assess the situation.
X	Face-to-face and radio communication: MIC directs the medical response and strategy.

[Table 3: Summary of the results in Section 5 tied to aspects of simulation validity.]

<i>Summary of the DiCoT models</i>	
Physical layout	The core artefacts of the simulation, the representation validity, consists of open low-fidelity vertical whiteboards and magnetic figures. Whiteboards represent locations or ongoing processes and figures represent patients and resources. The openness of these artefacts allow instructors to obtain an overview of the exercise state in order to maintain the situation awareness required to properly manage the exercise. Openness of artefacts in combination with the spatial layout might, however, cause overhearing and unrealistic situation awareness among the participants, reducing internal and external validity of the teamwork and command and control processes, but it might increase application validity.
Flow of information	As in real-life prehospital care, most communication in the ETS simulations takes place face-to-face or by radio (external validity). However, in real-life prehospital response, several IT systems are used to move and transform information that are not included in ETS, causing a reduction of internal and external validity. Some roles in the emergency medicine system are enacted by instructors aided by scenario scripts—making the instructors part of the simulation in order to enable external and application validity (by simulating communication between a participant and other agencies onsite). Participants use whiteboards as information hubs and as a means of making information public, transforming representations and contributing to the shared situation awareness. Artefacts can also be triggers of behaviour, such as the presence of patients, as well as triggers of immersion and as a means of ensuring external validity.
Artefacts and environment	The structure of the ETS system is flexible, but its low-fidelity constituents are static in nature and do not change over time. For instance, patient states never change, which reduces internal validity but might benefit application validity since it simplifies the task. Both participants and instructors make use of the flexible nature of the ETS artefacts to construct cognitive scaffolding. This, however, makes parts of the simulation hard for the instructors to control, such as information sharing and patient treatment, where it is easy to cut corners as a participant. This can be problematic for internal validity and for calculating the simulation outcome.

[Table 4: Digital redesign of ETS. The left-hand column indicates benefit, loss or both; the right-hand column describes the property affected.]

<i>Pros and cons of transferring ETS to a digital medium</i>	
+	More advanced simulations. The digital medium provides opportunities for realistic content, which can increase simulation fidelity and internal validity. In the ETS case, this could mean: including dynamic states of patients and environments, events, richer and more integrated media, and integration of existing IT systems. This creates new opportunities for immersion and for use of experience (see section 6.3.2).
+	Geographic distribution and other agency inclusion. As seen in the analysis, openness can cause unintended propagation of information (see Section 6.1.2). Using a digital medium, simulations can easily be distributed geographically to avoid this. This provides opportunities to distribute an exercise over several agencies in order to benefit inter-organizational teamwork; increasing external validity. Eliminating the need for instructors to manually move figures can also reduce unintended information triggers (see Section 6.1.3).
+	Setup and (re)play-ability. A lot of work is done before and after a simulation. In this case, setting up an ETS simulation takes a great deal of time and effort (see Section 6.1). By using a digital medium, a simulation can be set up and reset with the click of a button, enabling an exercise to be replayed several times. This would be beneficial to application validity and reliability.
+	Automated data logging. Giving feedback post simulation is important from a pedagogical standpoint. Data in a digital system can be automatically logged (including data that were previously impractical to log), which provides instructors with more time for management and role enactment (see Section 6.3.1). Structured logs can increase application validity and internal validity, and can be used for verification.
+	Simulation control. A flexible simulator gives participants freedom to act and improvise. However, low strictness (as observed in the ETS architecture) means that instructors have little control over variables that are important for simulation outcome (such as treatment times, patient positioning and whether prerequisite resources are available for treatment; see Sections 6.3.1). In a digital medium, prerequisites for action can be enforced to provide more control over variables, enabling more accurate simulation outcomes. Such restrictions can increase both internal and external validity.
-	Loss of direct customization opportunities. Participants and instructors use the flexible nature of tangible tools to customize their work and create cognitive scaffolding (see Sections 6.2.2. and 6.3.2). Digitization may limit this possibility and reduce application validity.
-	Loss of improvisation opportunities. If a digital system is too stale and rigid, it will not leave enough room for improvisation during the simulation (see Section 6.3.2), reducing both external and application validity.
-	Loss of intuitive interaction. Tangible objects, such as magnetic figures and adhesive notes, are easy to use and understand (see Section 6.1.1). Digitization will cause a degree of opaqueness and abstraction. For instance, triage that is a transparent action in ETS will become more even more symbolic in the digital world.

10 Figures

[Figure 1: Physical layout of exercises E3 and E4. The thin rectangles represent whiteboards, while the rounded squares represent tables.]

[Figure 2: Spatial layout of exercise E1.]

[Figure 3: A partially covered accident site. A large paper sheet is used to hide Sector 2 of the accident site, preventing participants from accessing some of the patient group.]

[Figure 4: Patient treatment and triage. Adhesive labels represent treatments and triage of the patient.]

~~[Figure 5: A representation of an accident site in ETS. The open nature of the accident site enables the instructors to maintain awareness of participant performance.] DELETED~~

[Figure 5: Prehospital command structure and information movement. The dashed figures indicate roles typically enacted by an instructor. The squares represent typical whiteboards (wb) used.] (Previously figure 6)

[Figure 6: Patient count. A cognitive scaffold that transforms a mental task into a perceptual task.] (Previously figure 7)

[Figure 7: Accident site map. A map displayed on an accident whiteboard to trigger scenario immersion.] (Previously figure 8)

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Sektor 1 Plan 1

5 våningar

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UT-EXIT

UT EXIT

G13

Ligger
Tyst

A - OK

B - Tachypné

C - Blek

D -

E - Stora sårskador
båda benen

CASE

THH THH
III

Fotbollsgatan

S:a Arenan

TRANSPORTTIDER FRÅN SKADEOMRÅDE Simuleringsövning E

(skickat "svensk text" som "från och till" inkluderar avstånd
av patient och stansättning av ambulans)

Destination	Andersson		Hedberg	
	Enkel Sida (Svart)	Från och till (Svart)	Enkel Sida (Svart)	Från och till (Svart)
Stadskyrkan (1.5 km)	05	010		
Café (10 km)	040	150		
Stadskyrkan (10 km)	050	040		