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Computer-based 3D simulation: a study of communication practices in a trauma team performing patient examination and diagnostic work

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Abstract Diagnostic work in trauma teams is critical for the patient's condition and for the possibility of survival. It is a difficult situation to train due to the inherently unpredictable and time-critical practice when an injured patient presents in the Emergency Room (ER). Different types of simulations have been developed for specialized training of specific skills and on contribution to teamwork, but there are hardly any studies reporting on opportunities to train realistic, multidisciplinary collaboration and communicative skills in such time-critical settings. In this article we report on a collaboration-oriented simulation where a trauma team performs diagnostic work: examining a patient in an ER at a hospital. The setting studied is arranged as a design experiment and video data constitute the basis for our interaction analysis. Our main finding is that highly-specialized simulations are useful as an arena for communication training among trauma team members. Doctors and nurses manage to make the simulated representations relevant in their talk, share medical observations and examinations, and consecutively include these findings into their collaborative diagnostic trajectory.

Keywords Virtual world · 3D simulation · Trauma team · Teamwork · Collaborative problem solving · Communication · Diagnostic trajectory · Sociocultural theories · Design experiment · Interaction analysis

Introduction

When a patient enters the Emergency Room (ER) following an accident or trauma, time and competent judgment are critical. The trauma team's capacity to diagnose the patient correctly and quickly is decisive for prognosis and treatment, to reduce likelihood of

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consequences like persistent, long-term health problems or death. These high-stake situations are most often uncertain, with limited information, ill-structured problems, competing goals and providers that operate under their specific professional, organizational and cultural norms.

Trauma teams are highly specialized and trained for optimal division of labor between the members (Brattebø et al. 2001). The team members perform assessments, examinations or evaluations of ambiguous information continuously. Communicating the initial or preliminary findings of these examinations is a main challenge, yet considering the findings in relation to each other gives a basis for various decisions to shape the diagnostic trajectory and arrive at a final diagnosis (Sexton et al. 2000). Teamwork and team performance is crucial to problem-solving processes in complex cases, and observed adverse events or impeded patient safety originate more often from flawed teamwork and poor communication than from individuals' lack of clinical skills (IOM 2000).

A growing body of research on expertise in the medical domain documents that exposure to high numbers of practical experiences increases the capacity to examine patients and make the right diagnosis (Norman et al. 2006). However, due to the relative infrequency of trauma, coupled with a complex, dynamic treatment environment, along with the incoming patients' medical conditions, it is very difficult to train the required problem-solving and communication skills in an everyday, time-critical, highly stressful setting like the ER. Therefore, setting up simulation scenarios that emphasize technical and procedural skills acquisition is increasingly used to train surgery (Sakava 2008), invasive procedures (Seymour et al. 2002), and crisis management in anesthesia (Gaba et al. 2001; Manser et al. 2009). This body of research focuses on clinical performance as outcomes in terms of the individual's technical skills acquisition, embedded judgments and contribution to problem-solving. Studies reporting on preparation for and training of leadership, teamwork and communication processes in care teams, particularly during simulation, are scarce.

This article reports on how a team of health providers used a simulation environment to communicate, initiate examinations and share examination results during a diagnostic trajectory of a patient. After having gathered data from one simulation-training environment, we analyze how experts in a trauma team worked together during a diagnostic trajectory. The training environment was a computer-based 3D model of the ER and it was named after the project; Matador. This training environment was a distributed, virtual, highly specialized simulation of an ER where the participants—doctors, nurses and the patient—are represented by avatars. The Matador environment was designed in collaboration between doctors, nurses and researchers with background in medicine, computer science and learning specifically for the purpose of training professionals' leadership, teamwork and communication skills while making a collaboratively constructed medical diagnosis of a patient's condition.

Research questions

Common to studies of diagnostic work and temporality is the focus on communication problems. In healthcare, this problem is obviously linked to the coordination of examination data from patients. Members of multidisciplinary medical teams are well trained to perform various tests, but to collectively link information in the overall diagnostic trajectory is more challenging. This is even more so in emergency settings, where time really matters, and mistakes might have fatal consequences. The multi-disciplinary work involves participants who all have a medical background, but are specialized in different aspects of the medical field (surgery and anesthesiology). It is the complex task structure that creates the interdependencies between the participants. With this background, we pose our main research question:

- What characterizes communication between members of a multidisciplinary medical team in a simulated virtual ER?

Two sub-questions are generated: (1) How are the different types of examinations coordinated and taken up during collective diagnostic work? (2) How are the different professional visions expressed in the multidisciplinary team's interactions, and how do the medical representations become part of these?

Review of simulation environments in healthcare

Diagnostic work is a topic with which several researchers have been concerned within healthcare (Kane and Luz 2009; Poletti 2009). To train for specific skills as part of diagnostic work in medicine, simulation environments are seen as an attractive technological set-up to amplify a variety of real-life training experiences interactively without jeopardizing patient safety (Gaba 2004). These set-ups can be hybrid learning environments using partial task trainers or full-sized manikins (Sakava 2008), complex, human patient simulators (Laschinger et al. 2008), or virtual (reality) environments (Albani and Lee 2007; Huang et al. 2007).

The focus is, however, often on *individual's* training of technical skills and performance of procedures under varying levels of realism (Cherry and Ali 2008; Panait et al. 2009). The learners are exposed to simulation scenarios of infrequently occurring, complex, often lethal clinical situations; e.g., resuscitation in pediatrics (Weinberg et al. 2009), trauma care (Duchesne et al. 2008; Knudson et al. 2008), surgery (Sakava 2008), or anesthesia (Gaba et al. 2001; Hammond 2004; Manser et al. 2009). Even in crew-based, discipline-specific scenarios or multidisciplinary team training of diagnostic work and collaborative problem solving, the studies continue to report individual team members' performance and achievements in terms of knowledge, skills and attitudinal competencies (see, e.g., Gaba and colleagues' (2001, 2009) Anesthesia Crisis Resource Management (ACRM) studies or Paige and colleagues' (2009) multidisciplinary team-training of practical skills in a high-fidelity Operating Theatre).

Studies typically concentrate on *post-scenario debriefing* and opportunities for the participants to improve *individual performance* based on feedback and reflection (Lachinger et al. 2008; Youngblood et al. 2008). Studies report improved psychomotor skills and performance of invasive procedures like operative laparoscopy (Lucas et al. 2008; Seymour et al. 2002), or surgery in the operating theatre (Scott 2006) following exposure to simulation. There are also reports of outcomes in terms of high user satisfaction, higher comfort levels and self-efficacy (Hammond 2004; Lachinger et al. 2008). Most studies report that learners mastered key skills according to level of knowledge, and point out that the learners appreciate the learning experiences.

It is, however, unclear if simulation-based training of discrete tasks for technical, procedural or psychomotor skills can possibly improve conceptual understanding, critical thinking, or reflection, or how these skills can strengthen team performance in collaborative diagnostic work, for example. The collaborative aspect of how people communicate and perform as teams, particularly when using technologies, has received less emphasis. However, this theme has been acknowledged as an important issue (see Büscher et al. 2009), and it has been singled out as the next promising generation of simulation studies (Manser et al. 2009). We find a few studies on trauma team training and collaborative, multidisciplinary problem-solving in simulation environments that take communication processes as their analytic starting point. These studies share the same theoretical and methodological interpretation as our study, and thus they are important as input in our research.

Kane and Luz (2009) focus on collaborative work during a multidisciplinary medical team meeting to create a shared understanding of a diagnosis. The meeting takes place using a teleconferencing system consisting of a microphone, a document reader, a PC, a SmartBoard™, and a plasma screen display. Based on ethnographic data, Kane and Luz concentrate on how the different participants bring various "professional visions" into the diagnostic work. The concept of professional vision can be seen as a key concept for understanding experts collaborating in communicative practices (Goodwin 1994). Following Goodwin's claims, consideration of a problem should be understood as a socially situated, historically constituted body of practices. This involves the interpretation of different types of medical signs (e.g. clinical, monitoring of biological data like blood pressure and lab-data) and discriminates between them through the diagnostic trajectory. In this sense, an agreed diagnosis is achieved through dialogue by means of signs, where knowledge from the dialogues merges. Kane and Luz argue that the technology they studied, teleconferencing, makes it possible to coordinate different professional views and that a diagnosis becomes more reliable through this practice. They further claim that the reason this system succeeds is that it supports individual professionals in their use of large image data, group interactions through dialogue, and possibilities for sharing the fine-grained, detailed information necessary for diagnosis.

Reddy et al. (2006) describe how medical workers in a surgical, intensive care unit, focusing on how individual strings of action are organized to achieve collective ends. Through their study of individual information-seeking and how information is shared over time, which means that important steps in collective interactions become transparent. They argue that the main challenge in medical work is linked to the organization of the shifts between the individually collected information and the collective coordination and understanding of this (Reddy et al. 2006).

Drawing on two studies with low- and high-fidelity simulation scenarios, Rystedt and Sjöblom (2009) maintain that simulation can be a professionally relevant activity, depending on the interplay of the simulation scenario, the technological environment's ability to present realistic situations and participants' knowledge and prior experiences. The professional relevance sits in the interplay of contributions to understanding the specifics as they unfold, displayed in co-participants' succeeding turns and efforts at communication that maintains a common picture of the unfolding situation (Rystedt and Sjöblom 2009). This points to challenges in representing practices in a simulation environment, and we will further develop this as we discuss our theoretical and methodological approach.

Theoretical and methodological background: a sociocultural approach to understand a diagnostic trajectory

In most studies of medical expertise the unit of analysis is the individual; their cognitive structures and how they organize their knowledge is defined as an individual kind of expertise. When the focus is on how experts coordinate and communicate, we need a unit of analysis that makes it possible to understand the social interactions between the involved *actors* and the *tools*. Therefore, our unit of analysis is the collective; how the participants as a team contribute to problem-solving by using different kinds of medical representations is understood to be the tools. In our case, communication practices are highly specialized. A sociocultural perspective on communication and reasoning opens the way to examining this kind of communicative practice. Communicative practices should be understood as multi-layered phenomena. Communication builds on what becomes relevant in the social interaction, how the participants contribute and how the social practices are organized. In social practices, specific resources are part of the knowledge infrastructure, and these resources can be activated by the participants involved in the interaction. Each participant can activate the resources that become relevant given a division of labor, and then the knowledge invoked can become part of the common reasoning. This stance towards communication practices implies interdependency between the persons, the others, objects and signs, which are the four constituents that become involved in collaborative activities. Linell (2009, p. 25) formulates it as follows:

> Meaning is both cognitive referential and sociohistorical; it is dialogical constituted, made in dialogue (cognition and communication), but this dialogical construction takes place with reference to the world and against the world and against the background of the world, which is in some sense already there, "out there."

The participants involved in this study drew on their experience and knowledge from a diverse set of medical practices that provides the resources for actual problem-solving. The signs (e.g., clinical, monitoring of biological data like blood pressure and lab-data) could be seen as the resources participants bring from previous, accumulated knowledge, as well as the medical information that is activated by the representations in the simulation. In this sense, the object is the diagnostic work, the signs are the respective bodies of specialized knowledge the doctors and the nurses bring into the ER, and the representations are, for example, the monitor.

Given that trajectories may differ in temporalities, the interpretations by the trauma team members are not a given, but must be seen as contingent in relation to the diagnostic trajectory. Professional visions are played out in communicative processes and give access to participants' orientations, repairs and gaps in relation to the interpretation of the signs. Orientation refers to how participants give direction based on the available information and knowledge in the unfolding diagnostic trajectory. Repair is related to processes when communication breaks down. In such diagnostic trajectories, tensions, breakdowns and gaps in communication are also part of the convention. This means that explicit checking out and repair are part of the medical practices, and participants establish the communicative means to make such moves in the talk.

Conventions in medical reasoning should be understood here as resources for collective memoration. Collective memoration does not imply that all the experts involved remember the same content and procedures and reason in the same way, but that exposure to certain problems becomes a part of co-memoration (Middleton and Brown 2005). The co-memoration is a temporary, shared set of processes related to a specific activity, like solving a medical problem. This view on memory does not question the knowledge that each expert involved carries with her or him between situations and activities, but argues that we must look at what the experts can achieve together through their interaction. Complex problem-solving involves the creation of a temporary social order. The participants involved create the social order based on which perspectives they use, i.e. their professional vision, the resources available and the social organization of the institutional activities. The principles of contingency, multiplicity and diversity serve as premises for analyzing and understanding communicative practices (Ludvigsen et al. 2011). We emphasize that the construction of common objects, physical and discursive, is crucial for productive social interaction to occur. When co-memoration becomes objectified, the participants create traces that can be followed, and it connects historical aspects with interactions here and now, all with an orientation toward the future in the problem-solving activities.

Research design

Design experiments, participants, and technological set-up

This article presents material from a project organized as a design experiment (Brown 1992). In the design experiment, an innovative trauma-team-setting simulation environment was engineered. A total of six teams tested the virtual world, which represented an ER at a hospital. Three of these teams were made up of students and three were professional teams with specialized nurses and doctors. Each simulation trial was moderated by a tutor. The participants played the roles of a trauma team: two doctors (a surgeon and an anesthetist) and two nurses (a nurse anesthetist and an ER nurse). They were geographically separated and connected by a broadband, Internet solution. Each team worked for about 30–60 min, which gave a total of six video recorded hours as the data corpus.

The team shared the same computer-based 3D model of the ER, and they could talk orally together through an IP system. All four team members and their tutor were present the entire time of the diagnostic trajectory. The virtual patient avatar responded with physiological changes depending on the trauma team's choices in the unfolding diagnostic trajectory. The empirical data for this article are video recordings of the seemingly most experienced trauma team's interactions during their examination of the injured patient, with which we analyze how the team arrives at a diagnosis.

The simulation resources

The computer-based 3D model was designed to simulate the activities that go on in an ER (for a complete version of the design process see: Berge et al. 2002; Halvorsrud 2002). This networked training environment focuses on leadership, teamwork, and communication within the team.

The simulated trauma setting and its resources are displayed in Fig. 1. In the upper part of the figure, we can see the computer-based 3D model of the ER. The avatars of the doctors and the nurses can move around, and the patient avatar is located on the stretcher in the middle of the figure. On the upper right-hand side, there is an electronic white board, the lamp in the ceiling above the patient avatar is the X-ray apparatus, and on the upper left-hand side of the stretcher there is a urine bag connected to the patient avatar's catheter. The time code in the upper right corner shows how far into the simulation the trauma team is. At the lower part of Fig. 1, there is a "roller blind system", which is where the team members can order specific examinations for the patient, for example HB (hemoglobin) or blood gas. The results from these examinations appear in the lower right-hand corner of the application, in the grey area labeled Results. The results only appear in the view of the team member who orders the examination. Results must be communicated to the team to be considered as a part of the team's decisions. The environment was designed in such a manner that each of the team members had their own particular perspective in the environment, based on the division of labor in real settings. The implication was that each

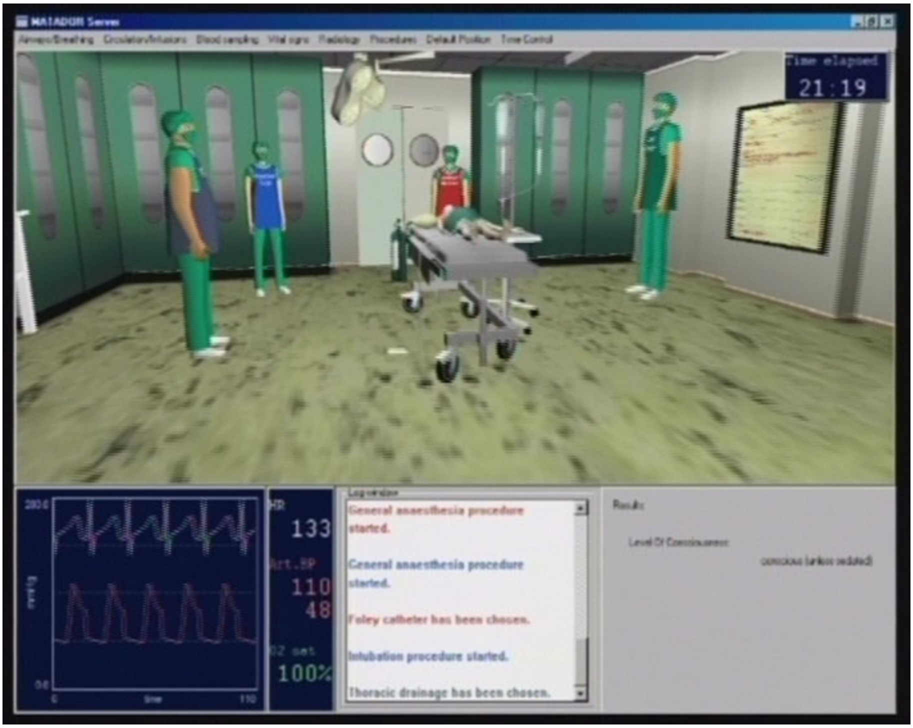

Fig. 1 The interface the trauma team members see when taking part in the computer-based 3D simulation of examining the patient

participant had to feed information and knowledge to the group as part of the diagnostic processes. Moreover, the monitoring system at the lower left-hand side of the interface graphically documents the patient's vital signs, e.g., pulse, heart rhythm, blood pressure and oxygen saturation. The small, white frame in the middle is labeled "Log Window." When activated, orders or central decisions (for example, that thorax drainage has been chosen) appear in the here. All elements of the interface, displayed in Fig. 1, come into play during the trauma team's examination of the patient and the unfolding diagnostic trajectory.

Data selection, analysis, and transcription methods

For this article, we chose to focus on one of the professional teams: the one that was the most experienced. This choice was based on the following criteria:

(1) Empirically, we considered this team best able to give us the richest data set for understanding what an unfolding diagnosis trajectory might imply.
(2) To the best of our knowledge, there are few if any studies of experts' collaborative work in medicine reported in the literature (the majority of studies are of novices and expert-novices). All the members in the team investigated in this study had more than 10 years of practical experience within emergency medicine.

Table 1 The distributed location of the trauma team in geographically separated rooms

Rikshospitalet University Hospital, Norway	Umeå University Hospital, Sweden
Anesthesiologist	Surgeon
Nurse Anesthetist	Emergency room nurse
Tutor (experienced trauma team doctor)	

Theoretically, the phenomenon we wanted to study was communicative practices among experts. In the team we selected for analysis, the participants were located at Oslo University Hospital—Rikshospitalet in Norway and at Umeå University Hospital in Sweden. The tutor was located at Oslo University Hospital—Rikshospitalet. This geographic distribution of doctors, nurses, and the tutor in the trauma team is illustrated in Table 1.

This trauma team's examination of a patient and the unfolding diagnosis trajectory lasted 35 min from when the simulation started. Just as in everyday practice, the team was lead by the surgeon. The moderating tutor was an experienced trauma team doctor who had taken part in the design work of writing up the simulation scenario and who knew the simulation in detail.

The data set covers the entire problem solving activity. The tutor's computer worked as a server, and it was the interface of this computer that was video recorded. The recordings made it possible to go through the trauma team's unfolding interactions repeatedly during our video analysis. This allowed us to follow the trauma team's interactions in terms of what they did and what they talked about in relation to the computer-based model and the disciplinary issues that this simulation was designed for. For the analysis, we will focus on how participants contributed as the trauma team gradually arrived at a diagnosis. The extracts constitute the basis for analysis, and are chosen because in different ways each constitutes vital observations, signs, and results of patient examination in the trajectory of the diagnostic process. We have labeled them as follows: (1) Vital signs and bruises, (2) Vital signs changes, (3) Further vital signs changes (deterioration), and (4) Setting diagnosis and choosing intervention.

We used interaction analysis to analyze the video data (Jordan and Henderson 1995; Krange and Ludvigsen 2008, 2009). This kind of analysis is well suited to studying details in interactions and meaning-making in and between settings. Moreover, it is particularly useful for studying interactions between participants (like members of a multidisciplinary trauma team) and computer representations that come into play in different ways by paying close attention to what they say and do.

In the transcribed extracts, information about how the team interacted with the mediating tools and how these tools were linked together in different ways has been marked *in italics* in the text. Information on the monitoring of vital signs is marked by Century Gothic bold caps letters, as in 120, 117 over 58, and 100 %, with reference to pulse, blood pressure, and oxygen saturation, respectively. Moreover, activities registered in the Log Window are similarly marked by Century Gothic caps letters: TORAX DRAINAGE HAS BEEN CHOSEN. Information from the Results window will be marked by Arial small letters: HB is 11. Shorter pauses are marked by "…" and longer turns that are left out are marked by brackets with time specification (35). Each utterance was given a reference number for use in the analyses. The level of detail in the transcripts aims to suit the depth of the analyses and to create a high level of transparency, so the reader easily can follow the talk and interactions (Mercer 1991).

The trauma team's examination of the patient and the collaborative diagnostic trajectory

In this simulation, the surgeon takes the lead and starts by emphasizing that he wants information about all observations, signs or results the other participants notice during the simulation. He underlines the importance of this, noting that this information is rich and should be shared with the team. Finally, the surgeon points out that if he does not reply when this kind of information is given, the other team members should interpret this as meaning that he did not hear what they tried to share, and they should repeat their messages.

The simulation starts when the paramedics bring the patient into the ER. The surgeon reads the description from the paramedics:

> This is a 12-year-old boy who was run over by a car. He was unconscious when the paramedic arrived 6 min later. He woke up tired and was subconscious 10 min later. He has no signs of injury, except for some bruises, and laceration on his legs and face. He was taken to the hospital's ER by ambulance. During the transport he got oxygen and half a liter of intravenous fluid. He arrived in the ER 30 min after the accident occurred.

Vital signs and bruises

As the simulation scenario starts, the surgeon first asks the anesthesiologist and the nurse anesthetist to take control of the patient's respiratory and circulatory functions and to check if he is conscious or not. The anesthesiologist replies that the patient is relatively stable, referring to the vital signs documented on the monitors: pulse 120, blood pressure (BP) 117/58, and oxygen-saturation 100 %. Second, reading the Result window, the anesthesiologist ascertains that the patient is responding, although he is rather tired and subconscious. Third, the nurse anesthetist gives the patient oxygen with reservoir and intravenous fluid, and reports that the skin is normal, respiratory frequency is 16, there is slight tachycardia, and HB [hemoglobin] is 11. The anesthesiologist sums up that since this HB value is somewhat low for a 12-year-old boy, this might indicate that he has internal bleeding from the accident.

Extract 1 below takes place about 8 min into the scenario, while the trauma team further assesses the bruises as a part of the initial diagnostic work.

Extract 1

1	Surgeon: On the right side it can looks like brusies, is it bruisers or just colors?
2	Tutor: …Move closer, then you can determine that. Especially where the brusiers are.
3	Surgeon: Moves closer to the patient's right side. Yeah it is bruises, right torso and right thotrax. I will try to get around … Soft voice as he orient himself in the application. Is it possible to move around for a closer look?
4	ER nurse: Is X-Ray ordered?
5	Surgeon: No, X-ray is not ordered. Then let us do that, that is good. Very good.
6	Er nurse: I will call radiology and ask them to come down [to ER].
7	Surgeon: Can i ask Er nurse to go look at the patient on the left side, since i am not getting over there so easily. Does he have blue lacerations-bruises there too?

Table a continued

8	Nurse Anaesthetist: Nurse anaesthetist would like to have a HB [haemoglobin] and order [blood type] screening.
9	Anaesthetist: We got HB, didn't we? It was 11.
10	Surgeon: Screening-that is the usual.
11	ER nurse: ER nurse moves closer to the patient's left side. He is blue at left side of the torso too
12	Surgeon: Soft voice He is in other words bilateral thorax contusion, so we can …sharper voice. Ok i will have this-I will have X-Ray.

There are four main themes in this extract: (a) *physiological functions* (utterances 8–10), (b) *actual examinations of the bruises* (utterances 1–3, 7, 11), (c) *preliminary diagnosis statement* (utterance 12), and (d) *identification of follow-up activities* pointing towards X-rays (utterances 4–6, 12). It becomes evident that each of the members of the trauma team brings unique experiences and specialized skills into the simulation. Similarly, it is the surgeon and the ER nurse who perform the actual examinations of the patient, looking for bruises and signs of internal bleeding. Individual expertise is evident when a participant in the simulation asks for specific tests or communicates observations out loud to the team (e.g. ordering of X-rays). The anesthetist's and the nurse anesthetist's observations of respiratory and circulatory functions are communicated to the team (HB value on 11), and the surgeon includes this information in the further assessment of the patient.

The use of representations becomes relevant through the strong role specification and the members' different professional visions. This means that it is the anesthetist and the nurse anesthetist who bring in vital signs values from the monitor, and it is the ER nurse who makes the X-rays relevant. Each of the team members' contributions are needed for the diagnostic work, but it is only through the surgeon's coordination of each member's contribution that the contour of the collective diagnostic trajectory takes form. As we have seen in Extract 1, the trauma team has taken one step further in their effort to examine the patient's possible internal bleeding by concluding "bilateral thorax contusion", meaning physical compression on both sides of the chest, and a possible closed wound leading to bleeding. This is the first precise hypothesis that is raised by the surgeon, which gives direction to the diagnostic work.

Vital signs changes

The trauma team continues their systematic examination of the patient by checking out different symptoms in the chest (thorax), which support the initial diagnostic hypothesis of possible internal bleeding. As the simulation scenario proceeds, the anesthetist reports that the patient is slightly tachycardic, meaning that his heart is beating rapidly, and the blood flow to the body is less efficient. However, he is still stable, but they decide to put the patient into narcosis. The surgeon orders a CT of the head, and the nurse anesthetist gets a blood gas of the anaesthetized patient to check if the patient has problems with oxygen. Thorax drainage is applied, and little blood and little air are observed from the drain. At this point, the surgeon asks for the status and about possible changes in vital signs. In Extract 2, we enter the data about 20 min into the simulation experiment.

Extract 2

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13 Surgeon: How is the patient?

14 Anaesthetist: Patient is circulatory stable. He is slightly picking up in frequency. PULS 130, BP 110/50, OXYGEN 100 %.

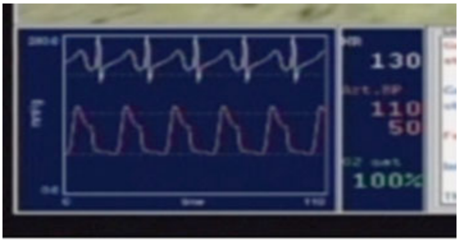

Figure 3 **Monitoring vital signs.**

15 Surgeon: He is picking up slightly in frequency, and falls in pulse, I have seen that too.

The previous substantiation of bruises on both the left and right sides of thorax was closed as part of the diagnostic work (see Extract 1). In Extract 2, there is only one pattern, *the physiological functions* (utterances 13–15). It is typical in specialized practice that it is the anesthetist who replies to the surgeon's utterances and brings this individual's knowledge up to a communicative level. The anesthetist ascertains that the patient is picking up in frequency (pulse 130, BP 111/50), and this is often the first indicator of possible progressive circulatory shock. Moreover, there is another interesting aspect that becomes evident in this short dialogue: the surgeon also keeps an eye on the monitor, but while the anesthetist does this all the time, the surgeon only does this when he makes the respiratory functions a topic of communication. In other words, his coordinating activities make him go in and out of the other trauma team members' visions. The surgeon does not follow each task moment-to-moment when the other team members either report unsolicited results or give answers when he has requested them.

Again, the representations (here, the monitor) play a central role in the multidisciplinary trauma team's diagnostic work. What is particularly interesting is that an additional aspect becomes evident in Extract 1, compared to Extract 2, which is that the representations play a double role in the trauma team members' diagnostic trajectory. They are not just a tool for the anesthetist, but also a shared tool visualized and professionally accessible for all the members' knowledge and memoration.

Further vital signs changes (deterioration)

The changing vital signs (Extract 2) lead the surgeon to initiate a complete re-examination of the patient, from head to toe, and he reaches a new intermediate conclusion in the diagnostic trajectory: he states that "the patient has a stable thorax." At this point in the re-examination, the anesthetist interrupts and reports that the patient's pulse is picking up and his blood pressure is falling—hence, they increase the intravenous flow. The patient has received almost 2 l NaCl (intravenous fluid), and the surgeon says they need to think about the blood (administering a blood transfusion). This is the situation when Excerpt 3 starts, 24 min into the diagnostic trajectory.

Extract 3

16 Surgeon: Then I push ”procedures” … “palpation of abdomen” … So i have to do that then Palpation of abdomen has been chosen. And now I touch the torso, and the program thinks for me.

17 Nurse Anaethetist: HB is 9 now. Reads from results window.

18 Anaethetist: Then we have to give blood.

19 Surgeon: Ok, then we have; my team—We have a progressive bleeding in a young man with a large physiological capacity. And he can have a comprehensive bleeding by this way, so let us order more blood…how much blood is ordered, anaesthetist?

20 Tutor: We do not order. We just, just give what is needed. And in the program you can give one unit or you can give two units.

21 Surgeon: I would give one unit non-negative, or one cross-matched?

22 Tutor: It is cross-matched for that matter.

23 Anaesthetist: He falls rapidly so we can start to give blood already, I think. BP 105/45.

24 Surgeon: I agree. And now he picks up slowly in heart rate PULS 135 and falls slowly in blood pressure 105/45. Okay.

25 Anaesthetist: Yes, Yes.

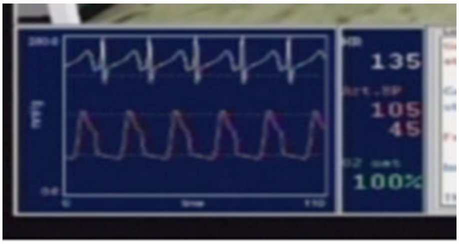

Figure 4 **Monitoring vital signs.**

26 Surgeon: I have the result from palpation of his torso. Findings displayed in his result window. He, he is tight, he is tight across the stomach, yeah, he is tight across the stomach. The implication is that he can have an intra-abdominal bleeding.

In this extract, there are three patterns. There is the *examination of the abdomen* (utterances 16, 26), followed by *physiological* (*circulatory and respiratory*) *functions* (utterances 17–18, 23–25), and *diagnosis statements* (utterances 19, 26). It is interesting to see how the conclusion that the patient has stable thorax contributes to ruling out one possible diagnosis, thus leading the surgeon to examine the abdomen. At the same time, the nurse anesthetist (utterance 17) follows up her professional vision, reporting that the HB has fallen from 11 to 9. This confirms the hypothesis of internal bleeding, and the surgeon brings this individual information up to the collective level, concluding that the patient suffers from a progressive bleeding (utterance 19). When the vital signs reported by the anesthetist also point in the direction of critical bleeding, given that BP has decreased from 110/50 to 105/45 (utterance 23), and the surgeon follows up by reporting that the pulse has increased from 130 to 135 (utterance 24), the achievement of an intermediate diagnosis is not far. The surgeon suggests that it could be an “intra-abdominal bleeding.”

In this extract, the representations are acted upon by the different participants based on the division of labor. It is the communication processes that leads them to the hypothesis, or what we call their professional vision. It is clear that all members of the trauma team made efforts to bring the results up to a communicative level (utterances 17, 23). According to the conventions, the surgeon coordinates and sums this up consecutively (utterances 24, 26). Similarly to what we saw in Extract 2, the anesthetist reports on changes in vital signs, and the surgeon turns his attention towards the monitor to follow up and adds information about the increasing pulse to the blood pressure observation (utterance 24). He also adds that the results from the palpation of his torso, or more specifically, the abdomen may indicate intra-abdominal bleeding (utterance 26). However, they still have not reached a final diagnosis.

Setting diagnosis and choosing intervention

The team members continue to observe the patient's vital signs. The patient is given blood. The surgeon continues the head-to-toe reassessment of the patient as he searches for the site of possible bleeding. In this last extract, the surgeon leads the diagnostic work by gradually closing different possibilities as they move towards a final diagnosis. Excerpt 4 starts 30 min into the simulation.

Extract 4

27 Surgeon: We have a suspected head injury and possible intra-abdominal bleeding. He has no bleeding in compartmental thorax, no bleeding in compartmental pelvis, he has no bleeding in compartmental long limb bones. It is unlikely that the bleeding is in compartment E6 outside Olso, but he can have an intra-abdominal bleeding. Then i would like to do a diagnostic laparoscopy. Can I do that? Or, speak load Leonard [addressing tutor].

28 Tutor: Yes.

29 Surgeon: Then I will explore presence of blood in abdomen. And now I do that.

30 Er nurse: We have information from radiology that they are ready, when we are ready to come up.

31 Surgeon; Okay, then we do the following; if the patient is stable we go up to radiology. If we stabilize the patient with this blood, then we go to CT, trauma CT, if he is not stabilized then we go to operating theatre.

Figure 5 Monitoring vital signs.

32 Anaesthetist: Now he is picking up rapidly in frequency. PULS 156.

33 Surgeon: Okay, then we see that he is less stable although we give him blood.

34 Anaesthetist: Should we give two units maybe?

35 Surgeon: Okay, Continue with blood. His respiratory rate is picking up. But that is controlled.

36 Anaesthetist: Yes, it should be controlled.

37 Er nurse: Unclear

38 Nurse Anaesthetist: I ordered additional blood down, down to the ER.

Table d continued

39	Surgeon: That is good. And can the Er nurse call the operation theatre to …intensity picks up … prepare for acute laparotomy.
40	Er nurse: I'm calling up [to operating theatre]. (5)And I prepare everything of medication, intravenous and portable equipment togo to further examinations.
41	Surgeon: Ok softer voice (5) It is a little unusual that children respond so poorly on blood, but okay, had it been an adult then it had of course been … Then we know , now I have the answer from the laparoscopy result, that it is blood in the abdomen received message in grey window. … It has been an intra-abdominal bleeding that does not respond to first bolus of intravenous fluid and that does not respond to bolus of blood.
	Surgeon continues: That means that there is an indication for laparotomy for this patient. I want to take the patient to the operating theatre. Laparotomy has been chosen [The problem/is solved and the patient is saved]

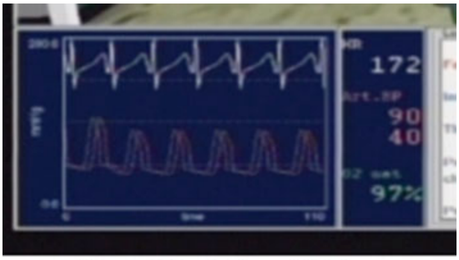

Figure 5 Monitoring vital signs.

There are four patterns in this extract: (a) *further examination of the patient and demarcation of the problem area to the abdomen* (utterance 27, 41), (b) *circulatory functions for stabilization of the patient* (utterances 31–39, 41), (c) *preparation work for follow-up activities in regard to alternative diagnoses* (utterances 30, 39–41), and finally (d) a *concluding diagnosis*, which determines the medical follow-up activities (utterance 41). These four patterns are tightly knit, where institutional practices, participant's experiences, and individual expertise are brought up to the level of collective diagnostic work. For example, the surgeon brings in everyday procedures from ER settings, repeatedly examining the patient and gradually demarcating the problem area to be the abdomen (utterances 27, 29). With the reported values of the patient's increasing pulse, from 135 to 156, the BP still low, at 105/45, and the marginal effects of the treatment with intravenous fluid and blood transfusion, the surgeon suggests two alternative follow-up activities (utterance 31). If the patient is circulatory stable, they go to radiology for further investigations, and if not, they go straight to the operating room for surgery. Again it is clear that the anesthetist brings his individual expertise up to a communicative level and that the surgeon includes this information in the overall diagnostic work (utterances 32–38). The anesthetist's information about the patient's circulatory status is of vital importance and constitutes the basis for the surgeon's final diagnosis to decide upon the follow-up activity: "going to the operating room" (utterances 39, 41).

Again, we can see that the representation, the monitor with vital signs and the participants' grey window, offer information that is used individually but brought up to a collective level and included into the diagnostic work (utterances 32–41). In the communication, the team members act upon available signs produced by others. What becomes particularly evident in this extract is how the surgeon brings all of the threads from the previous examinations and treatment of the patient together. In doing so, the participants' special, individual expertise is brought up to the communicative and collective level as they act on observations and continue the strings of actions in the unfolding, diagnostic trajectory. In this team of experts, their smooth operation implies efficiency in treatment and time-saving to arrive at the diagnosis and to set course of action.

Discussion and concluding remarks

The research questions raised aim to give new insight into how a team of experts in a simulated ER at a hospital delimit a diagnosis together, a diagnosis that none of them can identify on their own. The three main aspects that we address here are: (a) how the coordination is performed, which means the uptake of communication from others, (b) the timing of the problem-solving process and (c) what characterizes the communication practices in the team. References to the representations in the simulated ER are relevant for all three of these aspects.

Our analysis of this simulation scenario reveals that the trauma team follows four sub-trajectories in their communication processes and diagnostic work. These are:

- To monitor the patient; physiological (respiratory and circulatory) functions.
- To examine the patient; bruises, examination of the thorax and abdomen, demarcation of the problem area to the abdomen.
- To identify follow-up activities; X-ray, HB and blood gas values.
- Problem-solving—diagnostic work; preliminary diagnosis, diagnosis statements, alternative diagnoses and concluding diagnosis.

Thus, the whole diagnostic trajectory can be seen as four sub-trajectories. When monitoring the patient, the experts focus on the vital signs and the physiological status of the patient, and they refer to the same types of representations (BP and pulse) throughout the entire communicative process. The sub-trajectory "examine the patient" starts with the visible signs—the bruises—and gradually becomes more localized to a specific part where the problem is. The sub-trajectory "follow-up activities" contains the different tests and examinations, or a collection of signs the trauma team seeks and includes in the collective diagnostic trajectory. These three sub-trajectories are taken up, and this leads to the intermediate conclusions in the fourth sub-trajectory; "problem-solving—diagnostic work." Looking at how participants orient themselves towards the other participants, act on representations and interpret signs when these sub-trajectories intersect opens up more layers of communication, which are necessary to handle the complexities in experts' problem-solving processes.

These sub-trajectories should be seen as communicative patterns that become constituted through sequences of actions and the uptake of these signs over time. This means that the sequences of actions combined and "loop" back and forth in time when the surgeon suggests a hypothesis that gives direction to the work. The looping back implies that the signs have also changed meaning, depending on which other signs the participants treat as relevant for the diagnostic work. The implication of this is that the representation changes in function over the course of communication. The inherent features in the representation may remain the same, but their meaning changes in interaction with the diagnostic trajectory.

As the sub-trajectories intersect, the individuals' expertise interacts and constitutes the communication that makes it possible to solve the problem and delimit the diagnosis. More importantly, the intersecting sub-trajectories elaborate on how team members also mobilize prior experiences and familiarity to create collective meaning (Rystedt and Sjöblom 2009). Since these sub-trajectories differ in timing, the interpretations of what is produced when they intersect are not given, but must be seen as contingent in relation to the diagnostic trajectory (Ludvigsen et al. 2011). The monitoring sub-trajectory, overseeing signs and representations of physiological functions, operates on a longer time-scale, as representations of vital signs are visible and developments in this realm are brought to the team's attention throughout the simulated task. Similar to what was found in Kane and Luz's (2009) study, it is evident that the simulated representations support both individual and collective activities and make it possible for the participants to share fine-grained, detailed information.

As the participants in this simulation interact, they mobilize their knowledge and expertise. In their contributions, their professional visions (Goodwin 1994), or socially situated, historically constituted practices, come into play. Individual experts are characterized by their capacity to act according to specific patterns that the patients goes through; this means that they are strongly future-oriented in models of the patients' trajectories. When working in a team, these future-oriented trajectories are based on experiences and what we call "conventions" in medical reasoning and practice. Such conventions are a mix of the medical knowledge, the division of labor, and leadership. Their prior experiences, familiarity, knowledge and the context lead experts to activate and make relevant knowledge when acting on representations and signs in situ as the simulation scenario unfolds. In their communication practice, fine-grained, detailed information is a contribution reflecting each participant's professional vision, as taken up in the team's collaborative work (Goodwin 1997; Kane and Luz 2009; Reddy, et al. 2006). The reasoning processes involved in interpreting the data mainly follow one of the expected diagnostic trajectories. This is crucial for the team's performance and exemplifies a communication practice constituting an interplay in which individual expertise is taken up as collective expertise to solve the problem, and also picked up and refined further as the participants mobilize more disciplinary knowledge that is formulated as part of the collective diagnostic trajectory. As such, the unfolding interactions and the intersection of individual and collective expertise can be seen as resources for collective memoration (Middleton and Brown 2005).

Each sign represents cues for memoration about the unfolding trajectory of previous patients. The actual contingencies must be solved and the frame of relevance created in each particular case. This is also an example of conventions in the specific practice, where the interdependency of the participants in the simulation, is played out through signs and objects in the dialogue (Linell 2009). The medical information and the interpretations become objectified through social interaction during the problem-solving activity. The gaps are closed by following the sequences of actions that address the direct connections between the communicative means, and the "loop" that works across the sub-trajectories and in the diagnostic trajectory as a whole. So the gaps close at the action level and at the level of diagnostic trajectory. Moreover, the tutor's actions are an example of how gap-closing is accomplished as part of the communicative processes: by giving and adding information and through confirmation of the direction of the activities. From a more design point of view, he is also adding the information needed to make the simulation work.

The terms "contingency," "multiplicity" and "diversity" are the theoretically based concepts that we use to understand and explain communication practices in the expert team. The analysis shows that there is no uniform way of solving complex problems; even experts with long-term experience in a field need to communicate with colleagues in order to find solutions to problems. The signs and representations have a meaning potential that creates the historical understanding and direction for sequences of actions, but in complex problem-solving each participant comes with different forms of knowledge that must be communicated and made sense of in order to create temporary shared understanding. This means that the representations themselves are contingent upon the activities performed; in other words, they change in their meaning potential in a way that is dependent upon the frame of relevance in the diagnostic trajectory. It is through the intersecting contributions from each team expert that we explain how communicative practice leads to problem solving. The concept “contingency” makes it clear that each action could, in principle, be directed in another direction, but medical practices, as a set of conventions for problem-solving that embed knowledge and social regulations (division of labor), create constraints that keep the direction of actions within acceptable frames. It is within such frames the participants create their professional vision (Goodwin 1997).

Practical implications

Our main finding is that highly specialized virtual worlds, like this computer-based 3D model simulating a trauma team setting, have the potential to work as an arena for communication training among trauma team members. Doctors and nurses manage to make simulated representations relevant in their talk, share patient observations and examinations, and consecutively include these findings in their diagnostic trajectory. This is an approach to team-training and exposure to participation in highly specialized communication practices crucial to patient safety in complex, high-stake situations that might be promising for the future. This type of practice cannot be reduced to individual training and performance, since this is only the first step to a problem-solving model in which communication is the key to working out the complex problem at hand. One methodological implication of this is that post-scenario debriefing research designs are not sufficient to understand the communication challenges in trauma team settings. We also need research that scrutinizes the experts’ actual interactions during diagnostic work. For us, the solution has been to focus on the continuous movement between individual and collective examinations, tightly linked to dynamic representations in simulated virtual ERs.

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