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Emergent Coordination and Situated Learning in a Hybrid OR: The mixed blessing of using radiation

Abstract

Mobilising knowledge and coordinating actions in order to make use of new innovations and technologies is a major challenge in the health care sector. Drawing upon a longitudinal, qualitative study of a Hybrid Operating Room in Sweden, we illustrate how the staff from a variety of medical specialties need to coordinate their tasks and competencies, and learn how to use the technology in a safe way. This study shows that learning across highly-professionalised communities is a recursive process of emergent coordination and situated learning, which includes the acknowledgement of others' expertise, task interdependence, and the pragmatic accommodation of latitude and control. Moreover, there was continuous negotiations between the different communities about what should constitute approved practice based on the task being performed. This obstructed the development of a dominant community with the authority to independently exclude other communities. We thus conclude that emergent coordination of tasks and expertise is an important aspect of learning how to use technologies that break with conventions of established and previously separated practices.

Keywords:

Sweden, situated learning, communities of practice, emergent coordination, new technology, qualitative study

1. Introduction

Mobilising knowledge and coordinating actions in order to make use of innovations and new technologies is a major challenge facing the health care sector (Ferlie et al., 2012; Swan et al., 2016). Innovations and new technologies often break with the conventions of established medical practices (e.g. Barley, 1986; Beane 2018), which are based on knowledge situated within communities (Ferlie et al, 2005; Waring et al., 2013) and jurisdictions linked to medical autonomy and specialization (Currie & White, 2012). The increasing use of advanced technologies tends to push professional work towards more cross-disciplinary collaboration (Edmondson et al., 2001; Oborn & Dawson, 2010; Fenwick et al., 2012; Lindberg et al., 2017); however, restructuring work around new technologies tends to be difficult (Barley, 1986; Barrett et al., 2012; Waring et al., 2013;). Consequently, there is an increasing need for coordination and learning across disciplinary boundaries to make use of new technologies in local health care practices (e.g. Mørk et al., 2010; Valentine, 2018; Pine & Mazmanian, 2018).

A particularly useful perspective for understanding collective processes of learning in local practice, is communities of practice (hereafter CoP), which is defined by Lave and Wenger (1991:98) as "…an emergent activity system within which participants develop and share understandings concerning what they are doing and what that means". Such communities can be closely linked to the traditional medical professions or disciplines, but they may also cut across these if the practices or technologies they use require them to do so (Gherardi, 2006; Nicolini, 2012). Previous studies have shown that CoP members must continuously learn new skills, especially during technological transitions, to remain relevant (Barley, 1986; Beane, 2018). However, previous research has mainly focused on learning within CoPs, rather than on the processes involved when different groups and/or communities need to learn together (Edmondson et al., 2001; Gherardi and Nicolini, 2002a; Bechky, 2003;

Currie and White, 2012; Valentine, 2018). Learning across communities thus requires coordinating tasks and competencies.

Our study addresses how learning occurs during the introduction of new technology requiring the expertise of several CoPs to coordinate their activities. Drawing upon a longitudinal, qualitative study of a Hybrid OR in Sweden, we illustrate how the staff with different expertise must coordinate their practices, and learn how to safely use the technology. The potential of the Hybrid OR lies in its combination of advanced imaging devices and open surgery, requiring staff from anaesthesia, surgery and radiology working together. However, the imaging devices and the use of ionized radiation are a "mixed blessing": On the one hand, they provide the operators with sophisticated images; making it possible to perform cutting-edge medical procedures. On the other hand, the use of ionized radiation is potentially dangerous to everyone exposed to it.

This paper shows that knowing how to competently perform one's duties in the Hybrid OR is constituted *through* a recursive process of 'emergent coordination' (Okhuysen & Bechky, 2009; Bechky & Okhuysen, 2011; Bechky & Chung, 2018) and situated learning (Lave & Wenger, 1991) in the interstices between several highly professionalized communities. There was no distinct master-novice relationship between the experts from the different communities; instead, they engaged in a continuous *'act of balancing'* (Bechky & Chung, 2018) their freedom of action, based on their professional expertise, and control. This obstructed the development of a dominant community with the authority to independently exclude other communities (Mørk et al., 2010; Fenwick et al., 2012). Instead, emergent coordination and situated learning occurred in the interstices between several CoPs. Drawing upon the CoP and coordination literature, we conclude that taking advantage of advancements in medical technologies demands a 'constellation of interconnected practices' (Gherardi &

Nicolini, 2002a) that emerge from ongoing and recursive processes of coordination and learning.

2. Situated learning and coordination

The Community of Practice (CoP) literature conceives of learning as an integral part of practices which are socially, culturally and historically situated (e.g. Lave & Wenger, 1991; Brown & Duguid 1991; Wenger, 2000). The CoP literature focuses its attention on socialisation processes within established practices, described as "legitimate peripheral participation", referring to how newcomers are given simple (peripheral) tasks within the community to learn and (legitimately) contribute (Lave & Wenger, 1991). In CoPs, novices learn from experienced masters and other community members to become a competent practitioner (Brown & Duguid, 1991).

In most studies of learning in CoPs the practices and methods are well-known and approved (Beane, 2018). Lave and Wenger (1991: 97) distinguish between a learning and a teaching curriculum. The former "is a field of learning resources in everyday practice viewed from the perspective of learners. A teaching curriculum, by contrast, is constructed for the instruction of newcomers". Gherardi et al. (1998: 280) introduced the notion of the 'situated curriculum' to "…emphasize the fact that its content is closely related to the specific set of local material, economic, symbolic and social characteristics of the system of practices and work activities." Hence, learning is a practical accomplishment and should not be treated as separate from other organizational activities (Gherardi et al, 1998).

Several criticisms of CoP theory have been made. The original emphasis on negotiations and the role of power relations within CoPs are often downplayed (Contu & Willmott, 2003; Mørk et al., 2010; Nicolini et al., 2015), and learning tends to be assumed to occur in a one-way direction from outside-in as newcomers become inducted (Fenwick et al., 2012). Moreover, CoP literature is primarily oriented towards the social aspects without sufficiently accounting for the material aspects of work and learning (Fenwick et al., 2012). Gherardi and Nicolini (2002b) therefore underscore that practice, is not only learnt from people, but also from the artefacts used in practice.

Furthermore, most of the research focuses on what takes place within communities rather than across (Gherardi & Nicolini, 2002a). Valentine (2018: 572) therefore stresses that CoP theory "…offers insight into the process whereby people engaged in similar work learn to address shared problems, but it does not explain how interdependent communities learn and change together". Scant attention has been given to how learning plays out in situations requiring the expertise of several CoPs to synchronize their activities with a few notable exceptions. First, Gherardi and Nicolini (2002a) studied three CoPs in a building company and found that the dissonance and negotiations taking place when comparing perspectives in the constellation of practices were important for how learning occurred (p. 420). Second, Bechky (2003) studied how occupational communities of engineers, technicians and assemblers on the production line were able to create common ground and to transform understandings that enabled them to collaborate. Third, Oborn and Dawson (2010) studied how senior and junior members, from diverse medical communities, iteratively built, complemented, and extended each other's knowledge to co-create multidisciplinary work. Together they manifested a complementary and interrelated understanding, rather than a shared understanding.

Learning across communities also requires coordinating interdependencies, competencies, and responsibilities. During cross-disciplinary projects "people confront problems that are outside the realm of their competence but that force them to negotiate their own competence with the competence of others" (Wenger, 2000: 238). Accordingly, to address learning across communities, we extend the theory of CoP by drawing upon literature on coordination (e.g. Faraj & Xiao, 2006; Bechky & Chung, 2018).

Coordination is "the integration of organizational work under conditions of task interdependence and uncertainty" (Faraj & Xiao, 2006: 1156). Thus, it has to do with creating some kind of predictability when dealing with situations where there are novel task demands, emergent situations, and the unpredictability of evolving actions (Faraj & Xiao, 2006). Coordination is achieved via three mechanisms: accountability, predictability and common understanding (Okhuysen & Bechky, 2009), which jointly create the conditions for managing and integrating interdependent tasks. Several studies have illustrated how coordination unfolds across different communities, highlighting the management of task interdependencies and acknowledging others' expertise. Kellogg et al. (2006) describe how members from four communities coordinated their practices in order to make work visible, eligible and aligned as regards handling emergent interdependencies. They still experienced challenges relating to jurisdictional conflicts, misunderstandings, ambiguity and so forth. In a study of police SWAT teams and film production crews, Bechky and Okhuysen (2011) found that, through role shifting, reorganizing routines, and reassembling work, they managed to coordinate their expertise in order to handle the unexpected. These studies have made a significant contribution by showing how different groups coordinate their activities in order to manage uncertainty and interdependencies, and in order to develop mutual understanding across boundaries. Bechky and Chung (2018) stress that increasing occupational and organizational interdependencies requires *emergent* coordination. They show how members of highly professionalized communities, granted with significant latitude over their tasks, coordinated emergently to solve problems, developing a joint mandate to conduct their work. These studies have not, however, explicitly addressed whether or how learning occurs while coordinating. In her study of learning activities at a cancer treatment center, Valentine (2018) shows how multiple local groups synchronize their learning activities and renegotiate their spheres of obligations, which are associated with hierarchical positions, in ways that bring about new or improved understandings and activities. Edmondson et al. (2001) have also described how introducing new technology changed the interdependencies between surgical team members, and show how learning occurred through practicing together before doing procedures, through learning by doing, and through reflecting upon their experiences. Taken together, this enabled them to be well coordinated. Coordination is thus, an important aspect of medical work, work which, although highly systematic and standardized, also involves ambiguous trial-and-error processes (Edmondson et al., 2001) and improvised action.

In line with the studies presented here, we focus on situated learning and emerging coordination among interdependent communities. Thus, instead of seeing learning as a cognitive process, and coordination as a priori 'design,' we take the perspective that learning and coordinating unfold in practice. Coordination may thus be described as "an emergent, temporarily unfolding, and contextualized process of managing inputs and articulating interdependent action" (Pine & Mazmanian, 2017:722) and, as we will show, pragmatically accommodating freedom of action and control (Bechky & Chung, 2018).

3. Method

3.1 Setting

This paper draws upon a study of a Hybrid OR at Sahlgrenska University Hospital (SUH), in Sweden. The imaging devices used in such settings give guidance during both minimally-invasive surgery and open surgery, and allows physicians and nurses from a variety of medical specialties to perform procedures using real-time image guidance. This requires work to be organized in a way that concentrates both staff and resources on the patient, instead of being determined on the basis of the traditional separation of medical specializations.

The management of SUH decided to establish a *generic* Hybrid OR, which means that the same room is used by different medical specialities who needs to learn how to interact and coordinate their activities in relation to the technology. The Hybrid ORs were set up on "neutral ground" at the hospital, due to the generic use of the room and due to the construction requirements. A Hybrid OR holds a huge amount of technology and medical apparatuses and devices. The configuration of the imaging equipment consists of the X-ray unit mounted on an industrial robot, the table, and the imaging software, computers, and screens. Taken together, this site provides a particularly interesting setting for examining how the introduction of new imaging technologies impacts learning and coordination across communities.

3.2 Data collection

We have done extensive fieldwork in the Hybrid OR, following "practices in the making". This required us to draw upon research methods that can access what people actually do in organizations (Yanow, 2006). We have used a combination of ethnographically-inspired methods, which includes field observations and shadowing, interviews and document analysis (Czarniawska, 2014). The study was approved by the Ethics Committee for Sweden, and informed consent was obtained from the participants.

Between 2014 and 2018, two of the authors have conducted 60 interviews (80 h) with nurses and doctors working in the Hybrid OR, but also with hospital technicians, physicists and representatives of the suppliers of the technology. On 20 occasions, we observed training sessions in the room (62h), and shadowed anesthesia, radiology and surgical nurses (48h) in their day-to-day work. Moreover, on 12 occasions, we observed medical procedures in the room (52 h). Furthermore, we attended numerous meetings and seminars, gathering documents such as annual reports, presentations, and publications. We recorded and transcribed all the interviews, and took extensive field notes during observation and shadowing sessions in the Hybrid ORs accounting for verbal interactions, the physical settings, and more generally the collective actions and interactions of the participants.

3.3 Analysis

The field material was analyzed by two of the authors during a continuous comparative process inspired by a grounded theory approach (Glaser & Strauss 1967; Martin & Turner 1987; Czarniawska, 2014). The overall aim of the research project was to study how to organize complex practices in the Hybrid OR. While in the field, it immediately became clear that, although the use of radiation had not been identified, prior to the research, as an area of inquiry, its pervasiveness and the obvious struggles the staff, from different medical specialties, were having with its use in the Hybrid OR made it an important subject for analysis. Several groups of staff had never worked together before and had not been using radiation. A lot of activities, and discussions among the staff, concerned the radiation risk, radiation protection, and how to use the imaging equipment. Not only were doctors and nurses from the different medical specialties (anesthesia, various surgical sub-specialties and radiology) involved, but also physicists and supplier representatives.

We started by reading the transcribed interviews and notes from our observations and then wrote category labels in the margins. The first categories included the restrictions and possibilities of the new technology, and the use of radiation. Other categories had to do with collaboration, time/sequence, and responsibilities. We then compared and discussed the categories and found that they were often connected to learning activities. We continued by focusing our attention on how the learning activities were organized, who attended, and whether and how the different groups interacted.

In the ensuing fieldwork, we proceeded to explore similarities and differences among the participants as regards how they interacted and connected/translated “the new” procedures, emerging in relation to technology and radiation, to their established practices. This fieldwork was informed by what we had found in our initial analysis and we then added questions regarding, for example, the sequence of tasks and responsibilities. During this iterative process, we were continuously developing the categories, writing "memos" about ideas regarding the categories and their relationships (Martin & Turner, 1986), and, further on, their connections to the literature. Another important aspect of analyzing the field material was our ongoing conversations with the participants regarding our interim findings, via both informal conversations and formal feedback sessions.

The categories constructed from the field material were further discussed and elaborated upon jointly with the third author, and connected to the CoP literature. However, we also found that the state of interdependence, not only among the doctors and nurses but also among the suppliers, technicians and physicists, all of whom related to the new technology in different ways, concerned the coordination of tasks, control, and discussions about their professional autonomy. We thus used the literature on coordination to interpret the material in these categories. This allowed us to reveal how learning occurred, in relation to both organizational and occupational coordination and in relation to the control of such activities. Taken together, the longitudinal field material allowed us to reveal how learning occurred across practices and over time. In the following section, we present our findings.

4. Learning how to use the imaging system in the Hybrid OR

The Hybrid OR is a unique setting featuring new sophisticated imaging technology and open surgery in a single room, and thereby also requires reconfiguration of staff from different communities. In the medical literature (e.g. Bonetti et al., 2010), Hybrid ORs are bestowed with visionary expectations regarding advancements in medical treatments that benefit high-risk patients suffering from complex problems. They are designed to be used for combining the practices of radiology, anaesthesia and surgery, using tools and equipment that are intrinsically interconnected and interdependent. The Hybrid OR not only includes several experts, it also holds several types of materiality: the medical tools and devices (including protection devices) belonging to each practice, and the new imaging technology and its equipment. The imaging technology (robotic x-ray) allows the production of different kinds of images by using ionized radiation: i.e. flat X-rays, fluoroscopy (a series of images – like a film), and producing 3D images. It thus provides great potential for image-guided medical procedures, but concurrently involves risk as radiation is harmful to living tissue.

The Hybrid OR will be utilized by a large group of doctors and nurses from different specializations, for both planned and emergency procedures, including a variety of medical procedures and patients that are in poor, and therefore also unpredictable, conditions. To become authorized for working there everyone needs to undergo training in radiation protection. The use of X-rays is regulated by both national and international regulations. The Hybrid OR is classified as a controlled and restricted area, marked with signs on doors showing that only authorized staff are allowed to work there. At the hospital, responsibility is strictly assigned to the Department of Medical Physics to inform about risks, to train staff in radiation protection and to measure the accumulated radiation doses on the individual level. Medical physicist (2) described it as follows:

> The room is special as it has this powerful equipment and we're obliged to inform staff about the risks and train all of them in radiation protection.

To work in the Hybrid OR all staff are required to take part in a variety of activities (on the need for a variety, see further Splig et al., 2012), comprising formal instructions, practical training sessions, and informal day-to-day "trial and error" activities. These activities, concerning more than 100 nurses and doctors, take place inside the Hybrid OR, and are conducted by medical physicists, sometimes jointly with experienced radiology nurses, and by the supplier of the imaging technology.

4.1 Learning about radiation and sharing space

In the Hybrid OR training is performed jointly to ensure that staff from different groups come together to learn about radiation and how to use the equipment. All of the staff working in the room are experienced within their different practices, but the imaging technology is new to all of them. While radiation protection is already an integrated part of the established practice of radiology, staff from surgery and anaesthesia have never, or rarely, worked in such an environment and been exposed to radiation previously. Consequently, the physicists have to organize training sessions for staff who have different tasks, experiences, needs and skills, and who use different kinds of devices.

The first part of the session is based on a generic regulatory framework of instructions and covers information about both the risks and the implications of exposure, as well as how to protect yourself and others. Through the instructions, the medical physicist draws on his/her expertise and jurisdiction, and explains the regulations and recommendations regarding radiation. Here we will describe parts of one session.

The medical physicist (1) starts by describing what makes the Hybrid OR a restricted area, and that the levels of radiation staff are allowed to be exposed to are being defined by international and national radiation safety agencies. Radiation includes a certain degree of unpredictability as it scatters when interacting with a patient’s body: the greater the radiation dose - the greater the scattered radiation, and the greater the body mass index (BMI) of the patient - the greater the scattered radiation. The medical physicist (2) describes this as follows:

> It’s a very small amount of radiation that collides with the detector. Approximately 90% of the radiation loses its energy within the body, so maybe

> there's about 10% left. Most of it will be collected by the detector, but photons act randomly: will they collide or not, where will they go?

To protect themselves the medical physicist urge all staff entering the room to wear lead aprons or vests and skirts. These are stored outside the room, and the nurses are encouraged to try them on. Many of them note that the protective clothing is heavy and that they will also feel hot when using it. Within the room, there is also a lot of protection equipment, e.g. rolling shields made of glass, roof-mounted shields, and lead curtains on the X-ray table to protect staff from scattered radiation. Moreover, the staff are required to use a dosimeter (a device for measuring exposure to radiation) at all times to keep track of the amount of radiation they are being exposed to. The dosimeters detect the radiation dose, which is then visualized on a display as a color-coded bar diagram. The basic idea is that immediate real-time feedback will make staff aware of how they are positioned and protected.

Depending on their role and proximity to the radiation source, the staff not only need to learn how to protect themselves, but also how to coordinate their activities, in relation to the protection devices and imaging equipment. To align the prescribed safety instructions with different medical practices, the physicists use the dosimeters to show how radiation exposure varies with people's position in the room, something which is also connected to the tasks being performed.

During the training session, the medical physicist (1) puts four dosimeters at different points in the room: One at the head of the table, where the anaesthesiologist is positioned, one on the side of the table, where the surgeon and radiologist work, and one behind the protection shield in the end of the table. Finally, she also puts one dosimeter at the side of the detector on the robot to give the participants an understanding of the degree of radiation not being absorbed by the detector. Then she does a rotation (a 3D-image which produces the highest dose of radiation) to illustrate how exposure to radiation decreases with distance and behind protection devices. In doing so, all of the participants can see how the dosimeters show different results on the screen: red for the unprotected one at the detector, and green for the protected one behind the shield. The dosimeters attached to the anaesthesia nurse and the doctor, being close to the robotic X-ray, turn orange as they were quite exposed to radiation. This makes several of the anaesthesiologists indignant. As one of them explains: “We aren’t comfortable with leaving the patient and standing behind a shield a couple of meters away, as the radiology and surgery nurses are able to do.” The physicist (2) then explains, showing how they can use ceiling-mounted protection shields to reduce exposure while simultaneously staying with the patient. A radiology nurse interrupts and says: “But the robot will be very close to the devices the anaesthesiologists use. We don’t want it to collide… Maybe you can move it back a bit?” The anaesthesiologist says: “Right, but we’re rather cramped regarding space. Let’s try”. Some of the participants start moving the devices into different positions in relation to the robotic X-ray. The space is limited, which requires negotiating the equipment into position. While doing this, they are also explaining their tasks and needs, which are not always obvious to others.

This shows that all of the staff working in the Hybrid OR need to learn how to use protection devices, and how to act safely. According to regulations, the medical physicists have the right to define appropriate ways of acting when using the imaging equipment. Thus, they represent a non-negotiable safety practice that always needs to be respected, stressing the restrictions emerging from the use of radiation. However, the physicists are not present during real-time medical procedures and only have a legitimate peripheral position (Lave & Wenger, 1991) in relation to the medical practice. Their authority and jurisdiction are mediated by the radiation protection devices physically present in the room and through measure to the exposure to radiation exposure (using dosimeters). This enables them to exercise control at a distance.

The medical staff, on the other hand, need to coordinate the restrictions entailed by radiation, regarding both tasks and equipment, with the needs of each other's practical requirements. In order for them to jointly utilize the potential of the imaging technology, they also need to learn how to coordinate the medical tools and devices used in their established practices (anaesthesia, surgery, radiology) in the rather limited space available around the operating table, the patient and the robotic x-ray. Based on their professional roles, they have the freedom to coordinate and adjust their established medical practices, while simultaneously exercising occupational control (Bechky & Chung, 2018) in situ. Together, the different communities agree upon a way of coordinating their tasks while simultaneously acknowledging each other's needs and expertise, thus aligning the safety practice with their medical practices.

4.2 Learning the imaging equipment: technological instructions and professional judgment

Producing images has been a matter exclusive to radiologists; today, however, many surgeons are using different kinds of image-guided techniques. The imaging equipment in the Hybrid OR is, however, advanced and unique and thus becomes the pivot around which physicians from various surgical sub-specialities need to learn how to produce images using ionized radiation.

In line with the contract between the hospital and the supplier of the imaging technology, the supplier not only delivers the technology but also provides users with training in how to use the robotic X-ray. As many different doctors are supposed to be working in the Hybrid OR, the supplier arranges half-day workshops for small groups of doctors giving generic instructions but also letting them test the technology. The supplier representative starts by giving a basic introduction to the imaging equipment, showing how the robotic arm, with its radiation tube and detector, can be adjusted. A supplier representative (1) explains how to use the control panel to the doctors:

> We also have organ programs (while pointing at the screen) which indicate radiation dose and image quality. Within each program, there are different levels so that you can start with a low dose, and then gradually adjust it if necessary. Hence, for this particular type of surgery, we may need this level while for another procedure, we need a different dose and image quality

The doctors gather around the control panel and try to steer the robot into different positions. They take turns trying to adapt the position of the detector to come as close to the patient as possible, to optimize the quality of the image, and to minimize scattered radiation. They also test the different menus containing pre-programmed protocols for the most common medical procedures, e.g. angio/neuro/orto. These include pre-defined sets of radiation doses, like how many pictures will be taken within a defined time interval (sequence) and how many seconds a sequence of images will last. Quite often, however, the protocols and radiation doses need to be manually adjusted for the individual patient in order to produce sufficient transmission through the object and to provide the image with a good contrast. The supplier representative shows the variety of options. Together with the doctors' they adjust the radiation dose. The generic instructions regarding the functionality of the technology need to be complemented with the doctors' information about the individual patients' physical and medical conditions, as well as how to adjust the technology to each medical procedure.

These introduction training activities are just a starting point, the supplier representative (2) is also present during real-time procedures in the Hybrid OR to assist the doctors in dealing with the technology.

> Two experienced vascular surgeons are discussing an image. One of them is certain about his interpretation, the other person hesitates. They decide to do another fluoroscopy using some other settings (dose and time interval). One of them walks to the control panel and changes the parameters. The supplier representative interrupts and suggests that he can blend in more on the specific part of the leg. This means the same radiation dose can be used but concentrated to a more tightly-defined area. "Yeah, ok! Show me how to do that", she agrees. Together they work on the control panel and test different ways of blending.

This example shows how doctors discuss the quality of the image, and that even though they belong to the same community, they need to discuss their observations. Being absolutely certain about their interpretation of the image was imperative even though they had to repeat the procedure. To produce a "better" image, they need to adjust and to interact with the supplier representative to learn how to make adjustments and to learn how to deal with the technology in real time. Their professional judgment defined the appropriate use of the radiation and the supplier representative supported them with more finely-tuned instructions.

During the real-time procedures, the range of possibilities becomes visible, but so too do the restrictions. The doctors' ambition to produce the "best possible" image need to be balanced with the medical physicist's concern about radiation safety, aiming for optimizing doses and making the doctors understand how they can decrease the dose while still producing "good enough" images. Physicist 3 described this as follows:

> Radiation exposure is a side issue to most doctors, there are so many other aspects they need to consider. And when it comes to using this equipment, they only think

> of the image – to make it as good as possible. So, getting the doctors to change the program and to use lower doses, that's a real challenge.

Teaching doctors how to manage and use the pre-programmed protocols of imaging technology is necessary, but not sufficient. The use of the equipment also needs to be aligned with the doctors' situated understanding of the patient, and the medical procedure. This involves knowing how to coordinate standardized tasks, e.g. positioning the robotic X-ray and using the protection devices, and knowing how to adjust the radiation dose for the individual patient. The doctors' overall responsibility for their patients, and for treating them, emphasizes their professional freedom to act; however, they also need to be in tune with regulatory and technological restrictions. The relationship between the supplier and the doctor thus shifts away from a master-novice relationship (in the teaching situation) towards an interactive and recursive process in which both parties contribute with their experiences and specific expertise (situated learning) to learn how to competently use the imaging equipment.

The imaging equipment reconfigures work so that it creates interdependencies between groups of experts, thereby taking a mediating role (Gherardi et al, 1998) by helping to negotiate and bridge the competing interests of producing high quality images, on the one hand, and radiation safety, on the other. However, the different communities' 'spheres of obligation' (Valentine, 2018) are neither renegotiated nor integrated into a shared understanding. Instead, we see that different experts develop a complementary understanding (Oborn and Dawson, 2010) of each other's tasks and professional judgments, as well as the technical requirements, and how to coordinate and combine these in new ways. Consequently, learning how to use the imaging technology is done among the experts from different communities and in relation to the technology and artefacts employed to carry out the work, in line with Gherardi and Nicolini (2002b).

4.3 Radiation in practice: interdependencies and learning in situ

All of the staff working in the room have been given radiation protection instructions, while all doctors have also been trained in how to use the imaging system. Despite these training activities, it is during actual real-time procedures that they coordinate their activities and competencies, while learning how to produce images. The next example illustrates how doctors, nurses, and supplier representatives work together in a Hybrid OR.

The Hybrid OR is not only used for standardized procedures but also for developing new medical procedures. Two doctors, one specialized in surgery and one in radiology, are conducting a joint research project with the aim of developing more sophisticated image-guided procedures for surgery. Performing such advanced procedures requires staff with many different competencies to be present in the Hybrid OR. All in all, fifteen people will be involved in the procedure. In the following, we present parts of our observations of this procedure:

> The procedure starts in the early morning (6.00 am), with anesthesia, surgery and radiology nurses preparing the room and the patient. The patient was in a poor condition and two anesthesiologists were struggling with how to anaesthetize him. Once the patient is under anesthesia, the radiologists and surgeons arrive (9.30 am) and start discussing how to make use of the previously taken images. Two radiologists are also present in the control room to assist during the imaging procedure. They are experts in the optimization of images, visualizing and enhancing relevant aspects of the body, and in combining and fusing images from different sources. A supplier applications specialist is also present in the room, assisting the clinical staff in their use of the imaging technology, and helping them to explore the potential of the imaging software. After some more preparations,

> the two surgeons start the laparoscopy procedure (12.00 noon). During this procedure, the operator decides to use the robotic X-ray to make a 3D-image to check the procedure so far and for comparing this new image with images taken earlier. This requires the robotic X-ray to rotate around the patient, thus initiating a number of activities aimed at making sure there is enough space around the patient and the table to be able to do this. The staff have to move out of the area around the patient and stand behind protection shields, and trollies with surgical tools and other medical equipment are moved, and loosely fitted hoses are strapped to the table, etc. To produce a 3D image of the abdomen, the patient needs to be laying perfectly still; thus, the anesthesia nurse has to create an apnea before rotation. When everything is ready, the chief radiologist looks around the room to check that all the staff are behind protection shields and then announces that a rotation will occur when the anesthesia nurse is ready. He specifically checks the protection shield of the anesthesia nurse as she is closest to the robotic X-ray and never leaves the patient when he is not breathing. She says "apnea" and then the radiologist pushes the button on the control panel. The robot moves over the table, assuming an isocentric position over the patient and then rotating. Once finished, the surgeons, radiologists and supplier's representative gather around the screen to discuss the image (1.30 pm).

This example shows how all of the staff involved in the procedure are specialized in specific domains and depend on the performances of others. They are all masters in one aspect while being novices in others. Many of their tasks are performed in sequence, based on established practices. This sequence frames the work practice, functioning as a mechanism of coordination and clarifying the responsibility for the tasks. For example, anaesthesiologists need to fulfil their procedures before surgeons can proceed with their tasks. Their tasks are sequentially interdependent and they acknowledge the expertise of others, but without entering each other's domains. Moreover, the participants from the different CoPs are also better able to understand and develop their own specialties by drawing on others' expertise. The surgeons develop their surgical skills, using images, by drawing on expertise made visible by medical physicists, radiologists, and supplier representatives.

The example also shows interdependencies based on close interaction were some tasks are performed together. They learn to incorporate the contextual constraints of the setting when using the equipment, for example making space for the imaging equipment and the protective devices, and to adapt to a potential conflict of interest or contradictions; in this case, between radiation safety and patient safety. It is through these lived, first-hand experiences that doctors and nurses from different medical specialties, develop their skills in dealing with the imaging equipment and producing images of good information quality. However, these processes also follow a recursive pattern. The supplier representatives were present both to assist staff but also to gain ideas regarding how to improve and modify the technology, e.g. as regards optimizing the imaging software. This interplay includes ongoing, emergent coordination of tasks and competencies during procedures.

The interdependence of tasks (both sequence and interplay) not only requires everyone to acknowledge each other's expertise (Wenger, 2000), but also understanding why and how certain tasks need to be performed. To make use of the opportunities provided by the imaging technology, the staff from the different communities working in the Hybrid OR jointly experimented and reflected. Adopting an encouraging interaction style (see Edmondson et al., 2001) enabled them to coordinate both the predictable and the standardized tasks of their practices, as well as the unpredictable aspects of performing advanced medical work. By aligning the different medical practices with each other, and with the safety practice, they are creating a 'common ground' (Bechky, 2003; Okhuysen & Bechky, 2009) for working in the Hybrid OR. This means that there are no explicit or stable "master-apprentice" relationships between them; instead, their expertise and hierarchical positions shift with the tasks being performed. In line with this, Bechky and Okhuysen (2011) found role shifting, the reorganizing of routines and reassembling work to be important aspects of coordinating expertise. Learning, and becoming a competent practitioner, requires coordinating at the interstices between several communities of practice. Taken together, this may be described as a 'situated learning curriculum', a pattern of learning opportunities, taking place through the engagement in practice (Gherardi et al., 1998) and learning from the technologies and material devises used in practice (Gherardi & Nicolini, 2002b) and the practical constrains due to radiation safety.

5. Discussion

This study shows how experts from different communities of practice jointly learn how to use the new imaging technology in the advanced and complex setting of a Hybrid OR, which is characterized by multiplicity of task interdependence and uncertainties connected to the use of radiation and treatment of patients in poor and often acute conditions. Knowing how to competently perform in the Hybrid OR is thus constituted *through* both emergent coordination and situated learning in the interstices between several CoPs. As a consequence of the learning *and* coordinating activities in the Hybrid OR a 'constellation of interconnected practices' (Gherardi and Nicolini, 2002a) emerges. The study thus contributes to previous studies of CoP and coordination, by showing how learning and coordinating are two entangled activities unfolding recursively over time.

In our study, learning and coordinating occurred via three processes which were of significance as regards how to competently perform one's duties in the Hybrid OR: (1) managing interdependencies and unpredictability, (2) continually balancing between freedom of action and control, and (3) acknowledging each other's expertise. All these activities are triggered by the introduction and use of new imaging technology, being restricted by the use of radiation and conditioned by uncertainties and unfolding in an emergent and recursive way. They are thus not to be regarded as different phases, as in many other learning process studies (e.g. Edmondson et al., 2001), but as different processes jointly and simultaneously contributing towards the emergent coordination and situated learning.

One of the main aspects of learning and coordinating in the Hybrid OR is the ability to manage *interdependence* and *unpredictability*. Coordination not only includes the task sequence; it may also, as Faraj and Xiao (2006) stress, include dealing with the situation when there are novel task demands and emergent situations, requiring experts to handle the unexpected, as Bechky and Okhuysen (2011) found. In the Hybrid OR, the medical procedures are less predictable than the more standardized medical procedures performed by a single community. The willingness of the different communities to participate is based on what they believe can be achieved by using the new imaging technology. In doing so, they are intentionally striving for continuously improving established procedures and for developing new ones by combining existing expertise in new ways. This creates interdependencies (see, for example, Kellogg et al., 2006) between the CoPs, but also emphasises the uncertainties involved in using ionized radiation, which requires continuous coordination and learning in relation to each situation. For example, learning how to produce images requires the coordinating of technical requirements, individual adjustments for the patient, and the expertise of several medical specialists.

In the Hybrid OR, the staff, like the medical staff in Oborn and Dawson (2010), rely on existing hierarchies when it comes to interpreting each other's understanding. However, to coordinate their different tasks, they shift between hierarchies and established routines, but without renegotiating their 'spheres of obligations' (see further Valentine, 2018). Hierarchy, argues Valentine (2018), tends to create tensions between control and autonomy. In highly professionalized settings, like advanced healthcare, such a tension may be managed by a continuous *'act of balancing'* freedom of action (latitude), based on experts'/professionals' roles, with using occupational and organizational forms of control (Bechky & Chung, 2018). Control is exercised on both the organizational level (overt), e.g. the safety instructions prior to authorizing staff to work in the room, and in situ (latent) between the different specialists, e.g. checking radiation protection and dosage use during each medical procedure. The different groups of experts in the Hybrid OR develop a shared mandate which includes the shifting of hierarchies and the positions between them.

The tension between autonomy and control is also connected to the new imaging technology. Beane (2018) shows how the introduction of new technology can reconfigure work in ways that concentrate control on experts. In the Hybrid OR, work is reconfigured in relation to the imaging equipment, concentrating and distributing tasks and responsibilities, and in doing so creating and clarify interdependencies between the experts from the different communities. The imaging technology becomes a mediator between different medical specialties (Gherardi et al., 1998) and it concentrates control and the authority to act to experts. This also includes knowing *how to recognise* both uncertainties and the unpredictable aspects of the medical procedures, requiring *a readiness* to continually renegotiate the sequence and interplay of the interdependencies. The experts from the different communities have the freedom to act, and to control the various aspects of their practice on the basis of their established professional knowledge, since their 'spheres of obligations' are associated with their hierarchical positions (see Valentine, 2018). Knowing how to balance freedom of action within the various types of control, which are embedded in the practice of making use of the advanced imaging equipment in the Hybrid OR, is thus essential to the ability to competently perform medical procedures.

Another significant aspect of the pragmatic accommodation of coordinating tasks and balancing autonomy and control devices, which influence learning how to work in the Hybrid OR, is *acknowledging others' expertise*. All of the participants were experts, and thus masters and "high-status" actors who were confident in their roles, but they were novices in relation to other aspects of this particular setting. To deal with problems and to seek new solutions outside the realm of their established competence (Wenger, 2001), doctors and nurses with different medical specialties negotiated their competence with other medical specialists, physicists, and supplier representatives. This shifting master-novice relationship made the experts, in line with Edmondson et al, (2001) and Valentine (2018), open to experimenting and reflecting by adopting participative and encouraging interaction styles. Gradually they created 'common ground' (Bechky, 2003; Okhuysen & Bechky, 2009) enabling them to collaborate. However, this does not imply that their roles are interchangeable; rather, we found that the different experts draw on their expertise and on a complementary combination of the different practices. A shared mandate for carrying out work emerges (Bechky & Chung, 2018). This entails not disrupting their established practices, as shown in Edmondson et al. (2001), instead needing to align their tasks, and to acknowledge each other's expertise, in order to build up and combine the practices.

Instead of defending their jurisdictions, in order to protect their autonomy and position, (e.g. Ferlie et al, 2005; Barley, 1986), they rely on the established jurisdictions of the communities to interpret each other's understanding, and to then translate that understanding into action during procedures (for a similar argument, see Oborn & Dawson, 2010). This includes confidently engaging with the knowledge underpinning one's own specialist practice while simultaneously having the capacity to respond to and interact with others' expertise in this local practice (Edwards, 2011). This also includes an ongoing balancing act between the freedom of action, based on professional jurisdiction, and occupational and organizational control. Thus, in line with Bechky and Chung (2018), the work done in the Hybrid OR is characterized by pragmatic accommodation rather than a struggle for control. Our study thus provides a more nuanced understanding of the interplay between on-going learning and coordinating in situ, an understanding which captures the complexity and dynamics of organizing practices in which there are many experts, new technologies, and interplay between interdependencies and uncertainties.

6. Conclusion

The study shows that in the Hybrid OR the staff of the involved communities were able to accommodate plurality and legitimate coexistence within their joint efforts, without creating a new and unified CoP, when using the new technologies. This formation of cross community learning and coordinating is close to what Gherardi and Nicolini (2002a) refers to as a "constellation of interconnected practices". A number of work characteristics help to foster this constellation.

Firstly, the multiplicity of the interdependencies, both sequential and interactive, involved in performing the medical procedures suggests that there are limits to the extent within which it is possible to accommodate and sustain the complexity and breadth of the expertise needed to perform the various medical procedures, within an isolated and unified community (Ferlie et al., 2005). Instead of defending jurisdictions in order to protect their autonomy and position, which medical disciplines often tend to do (e.g. Ferlie et al, 2005; Barley, 1986), our study shows that the interconnectedness of communities did not privilege one community over another. Secondly, there is no distinct master-novice relationship. Instead, there is a recursive and ever-changing master-novice relationship, on the basis of the task being performed. This includes shifting hierarchies and the continuous act of balancing freedom of action, on the basis of professional judgment and different forms of control. The development of a dominant community with the authority to independently exclude particular practices and knowledges is thus obstructed (Fenwick et al, 2012). Thirdly, the process of mastery shifts away from being mainly based on past merits towards being increasingly based on the ability to pragmatically accommodate task interdependencies, acknowledging and drawing upon others' expertise and shifting hierarchies (Mørk et al. 2010). Finally, taking advantage of advancements in medical technologies is a major challenge facing the health care sector (Ferlie et al., 2012; Swan et al., 2016), and one which requires the mobilising of knowledge and the coordinating of actions across communities of practice. We suggest that it is through a combination of emergent coordination *and* situated learning across communities that knowledge of how to utilize the potential of advancements in medical technologies arises.

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