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THE CHANGING NATURE OF EXPERTISE: INSIGHTS FROM THE CASE OF TAVI

Davide Nicolini

University of Warwick, Coventry, United Kingdom

Bjørn Erik Mørk

*Department of Strategy and Entrepreneurship, BI Norwegian Business School, Oslo,
Norway/University of Warwick, Coventry, United Kingdom*

Jasmina Masovic

Department of Informatics, University of Oslo, Norway

Ole Hanseth

Department of Informatics, University of Oslo, Norway

Corresponding author: Davide Nicolini, davide.nicolini@wbs.ac.uk

Citation:

Nicolini, D., Mørk, B. E., Masovic, J., & Hanseth, O. (2018). The changing nature of expertise: insights from the case of TAVI. *Studies in Continuing Education*, 40(3), in press. <https://doi.org/10.1080/0158037X.2018.1463212>

THE CHANGING NATURE OF EXPERTISE: INSIGHTS FROM THE CASE OF TAVI

In this paper, we interrogate the current views on medical expertise, and expertise more in general, by building upon the study of an innovative medical procedure called transcatheter aortic valve implantation (TAVI). We find that phenomena like TAVI require that we modify our traditional views of expertise to acknowledge its social, material and distributed nature. We also find that in the case of TAVI expertise feeds upon the broad circuits of knowledge created by the combination of professional relationships, social ties and, increasingly, economic interests. Becoming and remaining an expert implies not only being socialised in a local regime of activity but increasingly also participating in, learning to navigate, and exploiting alternative and potentially competing circuits of knowledge, which may be controlled by private companies. The case of TAVI helps us to appreciate expertise as translocal and connected phenomenon and foreground some of the implications of the emergence of proprietary circuits of knowledge.

Keywords: expertise; distributed knowledge; relational expertise; situated learning theory; technological change; medical education, professional learning.

1 Introduction

In this paper we ask whether some of the emerging economically driven ways of working and operating in many spheres of society require that we rethink and expand the concept of expertise. We do so by focusing on medical expertise and elaborating our view through the examination of the case of transcatheter aortic valve implantation (TAVI), an innovative practice in the field of cardiology. We find that medical expertise is socially constituted, relational, historically situated, and materially entangled. In addition, we also find that medical expertise is increasingly translocal, economically invested and proprietary. This in turn modifies the conditions required to become and remain experts. Although our conclusions are grounded in our case study, and ultimately it is up to future research to explore whether what we found in the case of TAVI applies elsewhere, we suspect that what is happening for medical expertise may hold true also for other domains of human activity.

In this paper we fully endorse the recent social, material and interactional turn in the understanding of expertise. Early studies of (medical) expertise were based on an individual perspective and focused on how mental processing distinguished the diagnostic performance of experts from that of novices (Chase and Simon, 1973; Elstein and Schwarz, 2002; Mylopoulos and Regehr, 2007). The introduction of “fluency” accounts of expertise rooted in the phenomenological tradition (Dreyfus, 2004; Winch, 2010; Kotzee, 2014) enriched this view by suggesting that expertise was the result of a personal, stage-based journey of learning that made practitioners less and less dependent on explicit deliberation (Dreyfus, 2004). However, both models were individually-based; they focused on routine and stable expertise; and mostly considered crafts and occupations which were long-established and highly institutionalised (artisans, chess players, virtuoso musicians, etc.) (Kotzee, 2012). As such, they were ill equipped to examine activities that take place at the intersection of social groups and that are in continuous and fast development such as medical practices. Scholars therefore

argued that to understand medical expertise in modern healthcare -- and expertise more general, we needed to reconceptualise it in ways that take into account its personal *and* its social, relational and material nature (Stevens et al., 2007; Garrett et al., 2009; Sanders and Harrison, 2008; Edwards, 2010; Kotzee, 2012; Fenwick and Nerland, 2014; Fenwick and Dahlgren, 2015). Our main contention is that such a turn is important but insufficient. Social, relational and material views fail to capture that (medical) expertise is also increasingly translocal, and economically invested, that is driven by economic interests and sustained by proprietary forms of networking and circulation of knowledge. The idea of translocality suggests that expertise exists in many locales at the same time. While each of these locales has its own trajectory of learning and history of collective refinement, the expert activity (both individual and collective) feeds upon the connections established and maintained with other places where the activity is carried out. The idea that expertise is increasingly economically invested suggests that connections and the circuits of knowledge that support the collective mastery derive not only from social ties and professional forms of association, but increasingly also from the establishment of proprietary, and often, competing networks and circuits of knowledge established to generate profit (Ramlogan et al., 2007). Becoming and remaining an expert in such conditions implies not only being socialised in a local regime of activity (i.e., learning and refining one's skills) but also participating in, learning to navigate, and exploiting alternative and potentially competing translocal circuits of knowledge controlled by private companies. Once expertise becomes proprietary, we observe the emergence of new possibilities but also profound changes in the nature and dynamics of expert knowing.

In order to build our argument in this paper we work through the case of TAVI, a new minimally-invasive technique to change heart valves without open heart surgery. We argue that TAVI constitutes a particularly favourable case to understand what and where expertise

is. TAVI is, in fact, a radical innovation that depends on recombining knowledge from different medical specialities. The field of TAVI is moreover changing rapidly due to continuous technology improvements, to greater experience with carrying out TAVI in different ways and at different locales. Importantly, some of these changes are fuelled in part by the competition between valve vendors who took upon themselves to organise and control how practitioners learn better ways of doing TAVI (Olsen and Håkansson, 2017).

In the next section we position ourselves within the current debate by referring to three turns in the study of medical expertise. We then show that the case of TAVI requires the expansion and integration of existing approaches and what this means for the understanding or expertise.

2 Three turns in the study of expertise

According to Hoffman (1996) many authors still view expertise as an individual phenomenon that can be described in terms of cognitive development, reasoning process, modification of knowledge structure or a combination of the above (see , e.g., Pillay and McCrindle, 2005). In this paper we adopt a different view. We refer to expertise as a form of socio-material mastery which is ostensibly exercised when accomplishing specific discursive, bodily or worldly tasks. Expertise as mastery is, therefore, refined over time and legitimated by a group of peers; it can be carried by individuals and inscribed in disciplined bodies, but expertise is not something that individuals possess. This view, which we broadly share with a number of other scholars (Lave, 1988; Engeström and Middleton, 1996; Garrett et al., 2009; Edwards, 2010; Fenwick and Nerland, 2014), is the result of three broad turns in the contemporary understanding of expertise. These can be characterised as the turn from attributes to situated performance; the realization that expertise is inherently mediated and entangled, and the decentring and socialization of expertise.

2.1 *From attributes to situated performance*

A first major expansion in the understanding of expertise took place in the second part of the last century. During this period, authors began to question the idea that human competence is constituted by a specific set of mental contents and static cognitive resources that a person “has” and that are “used” to accomplish work (Mylopoulos and Regehr, 2007). Underpinning this shift was the increasing acceptance of the idea that expertise, in general, and medical expertise, in particular, were conceived as practical accomplishments rooted in personal knowledge and acquired through personal experience. This view, that Winch (2010) calls the “fluency” model of expertise, reframed the concept of skill acquisition in terms of personal development, whereby deliberation is substituted stage by stage by practical understanding based on pattern recognition and aesthetic sensitivity. Expertise, conceived as fluency in the execution of tasks within a specified domain, is achieved through experience and reflection. Practitioners move from one level of skills to the next: novices, advanced beginners, competence, proficiency and expertise (Dreyfus, 2004). Contemporary versions of the fluency model add that expertise is a not final state, an enduring attainment that all practitioners could achieve ‘for good’. Expertise is always evolving and relative to specific contextual conditions; becoming and being an expert is not only a personal journey of learning, it is an unending journey that requires the willingness and ability to purposefully question existing skills and expand the existing knowledge base (Mylopoulos and Regehr, 2007; Yanow, 2015).

2.2 *From individual to collective and relational*

One of the main criticisms of the so called fluency model is that it is still individually centred (Kotzee, 2014). Being a skilful practitioner in fact necessarily entails being in good standing in a community of practitioners, so that what counts as expertise is socially

negotiated by everyone that has a stake in the practice (Lave and Wenger, 1991). This in turn requires the decentring of the common notions of mastery: "... mastery resides not in the master but in the organization of the community of practice of which the master is part" (Lave and Wenger, 1991: 94). From this perspective, expertise always includes a social dimension (Kotzee, 2012). Expertise thus refers to a specific regime of competence within which the expert has been socialised, to which she contributes and for which she is accountable. The regime, of course, changes over time so that what counts as expertise is continuously contested and actively disputed (Collins, 2001; Stevens et al., 2007; Sanders and Harrison, 2008; Mørk et al., 2008; 2010).

The idea that expertise is the property of a particular social milieu which allows the socialisation of novices and the development of skills through legitimate peripheral participation (Lave and Wenger, 1991) requires a revision of the fluency model (Winch, 2010). As Collins (2013) noted, once expertise is considered as the attribute of a social group, the progression towards higher levels of skills ceases to be seen as a linear stepwise trajectory and becomes a trajectory within a space of possibilities.

Moreover, once we decentre the idea of expertise, we realise that in most real world situations expertise entails the "collaborative and discursive construction of tasks, solutions, visions, breakdowns and innovations" within and across systems rather than the individual mastery of specific areas of relatively stable activity (Engeström and Middleton, 1996: 4). Relational agency becomes critical. According to this relational view expertise as a capacity arises when professionals bring their specialist expertise to bear in their joint actions (Edwards, 2005; 2010). In this sense expertise should be always conceived as inherently distributed (Hutchins, 1995), networked (Hakkarainen et al., 2004) and interconnected (Gherardi and Nicolini, 2002). Expertise, thus, depends both on the journey of learning of individual practitioners *and* on the capacity of the social group where they belong to become

increasingly skilful through processes of collective and inter professional learning (Edwards, 2005; 2010) or through the expansion of the competence of the local system of activity (Engeström and Middleton, 1996; Greig et al., 2012).

2.3 *From human-centred to sociomaterial*

Social and relational views of expertise often (although not always) limit their focus to interactions among humans but tend to ignore the historic material conditions within which expertise is accomplished. In short, expertise is considered as an accomplishment of humans working together. However, this is only part of the story; the relationship between humans and their environment is mediated not only through other humans but also through cultural means such as signs and artefacts (i.e. material devices skilfully built by humans). Through mediation, history, culture, institutions, and power are all concretely manifested in human action (Fenwick and Dahlgren, 2015). The skills and capabilities of actors are mediated and fundamentally transformed by the capabilities of the tools and instruments that they use in their work. Artefacts are, thus, not only integral in the accomplishment of expert activity, but they are constitutive of expertise itself, as they have the capacity to mediate into the scene of action the history of achievements and learning that presided to their creation and refinement

The expansion of the notion of expertise in order to encompass this moves us towards a mediated or entangled view, positing that material and social forces are mutually implicated in the masterful accomplishment of activities. The idea that expertise is necessarily “sociomaterial” also reinforces its situated and social nature. The artefacts used in any expert performance also establish a relationship between different social groups and different forms of expertise, which makes the idea of a fully individual expertise practically untenable (Kotzee, 2012).

In sum, the three turns above invite us to conceive expertise as personal *and* social, historically situated, relational, distributed, and materially entangled. In the rest of the paper we utilise this emerging approach to work our way through the case of TAVI. As we shall see, the TAVI case show that this characterization of expertise may still be incomplete. This leads us to develop what we call a translocal and economically invested view of expertise.

3 Methods

The point of departure for this research project was a grant by the Norway Research Council to study the process of innovating, adopting, organising and developing a radical new technology across different hospitals in Scandinavia. We started our study at Intervention Centre (IVC) at Oslo University Hospital (Norway). Our initial study gave us rich insights into the complex processes of development and adoption that seemed to explain the way TAVI came to be organized and performed at this site (Mørk and Hoholm, 2016). It also appeared that the activities at the centre often were closely connected to activities taking place elsewhere, both in time and space. We therefore started to “zoom out” (Nicolini, 2009; 2012) to trace the connections to the trans-situated practices and make sense of the wider picture. We visited nine other Scandinavian hospitals, interviewed over 35 key actors (the interviews lasted on average 60 minutes), analysed documents and observed procedures and some meetings. We also interviewed representatives from the two main TAVI valve equipment companies and attended several national and international TAVI practitioner conferences and events. These latter conferences and events were important as they enabled us to observe and talk to representatives from different hospitals in Scandinavia and different medical equipment companies, and to develop a better understanding of similarities and differences across sites. A summary of our data is provided in table 1.

Table 1 Summary of data

Interview data	30 formal semi-structured interviews at Oslo University Hospital with cardiologists, cardiac surgeons, technicians and radiologists 32 semi-structured interviews in other hospitals in Norway, Sweden and Denmark (names omitted to preserve anonymity). In addition, we interviewed representatives from the two main TAVI technology vendors.
Observational data	Observation of 120 TAVI procedures at Oslo University Hospital Observation of about 20 meetings & seminars Attendance to 4 major practitioner conferences All together over 1400 hours of observation
Documentary data	Analysis of documentation, especially protocols, publications, media coverage and especially materials used by vendors to promote their product

The analysis proceeded utilising the established conventions and practicalities of robust interpretive social science (Yanow and Schwartz-Shea, 2006). The research team mutually constructed a primary thematic structure. The themes reflected the ongoing concerns of practitioners such as contract negotiations, team relations, technology developments, local, national and international networks of communication etc. Once expertise and its particular translocal nature started to emerge as a topic of interest, we went back to our data and mined the field notes, interviews and document for relevant clues and meaningful events. Moving continuously between data and literature we started to elaborate the idea that previous theorization of expertise captures only in part what we have observed. We went through multiple cycles of analysis and reflection and we returned to the field and asked some of the practitioners for further information and feedback on our observations. The analysis continued well into the writing stage. Indeed, the feedback from the anonymous reviewers triggered a further cycle of data analysis and interpretation.

4 Findings: The expertise of doing TAVI

We start with a vignette from our fieldwork that takes the reader in the middle of TAVI action. We use the vignette to discuss the nature of expertise in the case of TAVI.

4.1 Doing TAVI

The hybrid operating room, a surgical room equipped with advanced imaging devices, is crowded today with over 15 people moving in and out of the room. As the operating cardiologist told us in the changing rooms, today for the first time they will be using a new “third generation” delivery system. The two operating cardiologists stand close to the patient. Next to them is a large screen where they can see what happens inside the body of the patient. A proctor, the “master” cardiologist is standing at one side. He flew in from Hungary where he has already been using the same system for a few months. His arms are crossed, his head slightly bent. The posture says “I am supervising“. A bit farther away another doctor, who is also a learner, even though slightly less advanced, observes the procedure in silence. Two other leading cardiologists will arrive halfway through the intervention to observe the critical part of the procedure – the positioning of the new valve.

Everyone in the team -- nurses, radiologists, and anaesthetist moves around in a well-rehearsed choreography, telling of the many procedures they already conducted together. The guiding wires for catheters and catheter sheaths are inserted into the body of the patient at his groin. The wire reaches the heart (we can see this on our monitor). When the new valve is moved into and through the body of the patient, the proctor, who until now has been looking from the side, moves closer to the patient’s bed. All glances are towards the X-ray video screen. The robot with the X-ray camera continues to move above the patient making silent buzzing sounds. On our screen we too can observe the catheter and valve moving inside the body, and then stopping. The operating cardiologist shakes his head. The other people in

the room stretch their necks to see what happens. The proctor points to the screen and speaks again. For the first time now he also points to the hands of the interventional cardiologist. He does not touch the catheter but he shows the practitioner how to move it ("Twist it this way, not the other... push it this way"). The operating cardiologist is extremely attentive, his glance fixed towards the screen while manoeuvring the catheter that controls the valve near to the patient's heart. He is now visibly concentrated, trying hard, and struggling just a bit. We hear the proctor saying "that is not bad...move it a little bit". The cardiologist moves the valve a tad; the valve needs to be positioned perfectly so that no blood refluxes in the heart. This requires physical force as the valve has to be pushed and pulled up and down the artery using the catheter it is attached to. He glances at his colleague and then the proctor. Then he says, "It seems okay...what do you think?" The proctor seems satisfied: "Yes, not bad". He turns around to the other operating cardiologist who has been sharing the procedure: "What do you think?" "Uh...yes...I'm happy with this."

After the heart is stopped by fibrillation to deploy the valve into its correct placement, the tension in the room eases. "Are you satisfied?" The cardiologist in charge asks the anaesthesiologist. "Yes, it is fine". Within seconds the scene dismantles. The cardiologists who came to witness the operation leave the room while chatting. The proctor and the application specialist praise the virtues of the new system and the innovations it carries with it: "the behaviour is more predictable...the shape of the valve changed so that it fits better to the inside of the artery... it can be repositioned easily...it takes less time". They seem genuinely enthusiastic about the new system and want to share their experience: "...it is much better at tracking its way inside the patient's arteries... but you have to relearn how to let it go by itself...it will find its way but you have to stop twisting right and left as you were doing with the old version."

4.2 TAVI: expertise as accomplishment

The vignette illustrates well that the expertise of TAVI is a learned accomplishment. Firstly, the vignette presents a scene of individual and collective learning. A very visible and well-structured social “community of learners” (Lave, 1998) is created by the practice of doing TAVI. At the centre of the scene are the interventionist cardiologists who manoeuvre the valve and delivery system and the proctor, that is “the master”. The proctor does not teach, rather he makes room for the apprentices to learn. The nurses, technicians and anaesthesiologists are acquiring experience by attending to their tasks. The other onlookers learn by occupying a peripheral participant role. They came here to learn by watching attentively, waiting for their opportunity to be at the centre of the action. Every aspect of this scene speaks of expertise as achieved by learning in and through practice.

Tacit, bodily and aesthetic knowledges are clearly involved here. Inserting a valve is not only about processing information but also about pushing, pulling and twisting. Positioning the valve in the “right place” is judged by asking “*are you happy with it?*”, rather than referring to rules and abstract criteria. Instead of deliberation we observe a rather fluid performance guided by the intuitive grasp of the situation – what according to the fluency model discussed above distinguishes between experts and novices.

It is worth emphasising that the two operating cardiologists, who are considered by everyone else in the hospital as experts, are also here to learn. In fact, the entire scene is deliberately constructed as a way for the experts to refine and update their competence by tapping in the latest technological development. In doing so the two eminent cardiologists accept to occupy purposefully the role of learners (we would hesitate to call them novices). The proctor explicitly verbalises this: “*you have to relearn how to let it go by itself*”. Becoming and above all remaining expert requires moving back and forth between stages of

expertise, continuous adaptation and deliberate search for opportunities to expand the boundaries of their competence.

4.3 TAVI: Expertise as collective and relational

The vignette also illustrates that TAVI is a collective accomplishment and the result of a joint history of learning that differentiates this center from all others. Indeed, throughout the procedure the patient was sedated but awake – a pain management strategy that has only recently been adopted at this specific site.

Performing TAVI requires the collaboration between the cardiologists and cardiac surgeons. Dozens of TAVI procedures carried out together helped the team to learn how to operate “in tune” (informant). The result is the highly choreographed performance captured in the narration.

The extent to which TAVI is indeed a collective achievement became especially clear in occasion of a small breakdown which we observed during one of the procedures. The problem emerged because the valve that had been ordered did not fit the size of the patient’s aorta. At this point Anne, one of the members of the team, got up and rushed to the storage room. She quickly returned with a large box which she opened in a hurry. She pulled out a new delivery system, dislodged the valve from the catheter and brought it to the crimping table for the nurse to prepare for use. When she was reassured that everything had returned to normal, she cleared out the boxes in front of the operation room and returned to her seat. The thing is that Anne was in fact an expert radiographer. Her ‘official’ expertise was to operate CTs and x-ray scanners and give access to the ‘inside’ of the patient. However, Anne here is displaying a different type of expertise. By participating in dozens of procedures and working as a team she learned to instantaneously recognize the demands of others and is oriented

towards providing support to the ongoing activities. In so doing she developed an additional type of expertise “based on confident engagement with the knowledge that underpins one’s practice... as well as a capacity to recognise and respond to what others might offer” (Edwards, 2010, p.13). Anne had developed what Edwards (2010) calls “relational expertise”. Relational expertise describes the capacity of some, but not all professional experts, to align one’s thoughts and actions with others in the course of an activity. By taking into account the motives of other professionals, it allows different experts who work together (as in the case of TAVI) to build common knowledge which in turn allows to make progress on the problem space at hand.

4.4 TAVI: Expertise as materially entangled

TAVI is not only a collective and social achievement. It is also a highly materially entangled affair. Human and machine must constitute a well-aligned configuration in order for TAVI to happen. The expertise of TAVI manifests itself through (and is made possible by) a functional collective of human and non-human actors, each performing a critical part of the work. Take away the fluoroscopy x-ray machine (figure 1) which allows a cardiologist to see what happens inside the body of the patient and TAVI becomes impossible.



Figure 1: TAVI as material entangled: the fluoroscopy x-ray machine allows surgeon to see inside the body (picture taken during field work used with permission)

Materials do more than simply contributing to the expert action by providing real-time knowledge of the state of the patient. The valve itself and the delivery device, which allows to reach the heart through a small keyhole incision on the thigh, carry on the scene the results of a long history of development, research and accumulated wisdom. In a real sense the expertise of TAVI strongly depends on social and material connections that extend beyond the specific scene of action.

5 The landscape of TAVI expertise: expertise as translocal and economically invested

Summarising from above, the case of TAVI provides support to the view of expertise as accomplished, social and material in character. No person can do TAVI alone and doctors cannot operate if the rest of the staff is not appropriately skilled. The expertise of doing TAVI

is also historically situated and evolving. Such expertise did not exist ten years ago and when TAVI was introduced the procedure started to change what it means to be a “good” heart surgeon or a leading-edge cardiologist. The expertise of doing TAVI is also materially mediated and entangled. Our practitioners were very clear that you cannot simply walk into another hospital and start doing TAVI. Equally, if you enter into an operating theatre that has the wrong (or simply a different) spatial arrangement your expertise temporarily dissolves. You can be an expert in one hospital but not in the next one. In theory, expertise is in the mind. In practice expertise is deeply entangled with the social and material setting where it happens and depends on a complex hinterland of other skills, other people and other processes and expertise.

The case of TAVI, however, suggests that this situated, social and material, yet still local, view of expertise tells only part of the story. While the expertise of TAVI was locally accomplished and manifested itself in and through a specific collective composed by human and non-human actants working in alignment, its existence overflowed the local scene of action. The nature, state and advancement of the expertise of doing TAVI could not be understood without making reference to other sites, other centers and the relationships between them. In short, the expertise of TAVI was the emerging property of a larger and translocal network and their relationships.

5.1 TAVI: expertise is more than local

Our study indicated that both the expertise of doing TAVI (i.e., the skills for doing TAVI in the best possible way) and the adaptive effort to improve these skills were shared by a large community of practitioners linked by a number of personal and professional relationships. The expertise travelled through connections established by individuals and technologies moving across sites but also in a way existed as an effect of these connections.

A clear way of establishing connections is when individuals visited other hospitals to learn about TAVI. In the Scandinavian setting we observed several such examples. For instance, one of the cardiologists from Oslo spent several months in Copenhagen learning TAVI. Later he came back and explained to some of the team members the important similarities and differences between the hospitals' use of TAVI. One of these differences was that they used a percutaneous closing device that made it possible to perform TAVI even less invasively. Moreover, this technology is similar to other techniques well-known to the cardiologists, and by using it the cardiologists can perform the whole transfemoral procedure without the presence of cardiac surgeons.

TAVI technology vendors and especially proctors, experienced practitioners with at least 50 successful operations under their belts who act as intermediaries of expertise on behalf of the technology producers and they establish and maintain networks of connections between sites. TAVI proctors are themselves TAVI practitioners at their local hospitals and some of the team members at our main site have travelled around the world to proctor in other sites. As evident in the vignette above, proctors play a particularly important role in circulating working knowledge and developing the joint expertise of the group. Proctors visit TAVI centers on a regular basis. They discuss the procedures and exchange information about other practitioners and hospitals, illustrate new ways of operating and disclose tricks to perform the procedures more successfully. By doing so, they are instrumental in establishing connections between sites and facilitating the circulation of expertise . Finally, connections are established and exploited in academic conferences and seminars where hospital practitioners and technology providers meet to discuss, comment, teach, learn, explain, introduce new products and, in the process, take home snippets of wisdom, hints, and ideas that they can use in their daily work. The process of learning through borrowing the secrets of the art by watching closely, as described in the vignette above, extends well beyond the local

community of practitioners and learners. The community of practice created around the acquisition and development of the expertise of TAVI overflows the local scene of action. In a very concrete sense, the expertise of TAVI is also decentered. Both individuals and technologies are travelling across sites, and no single hospital or vendor could argue that “this is the way we should do TAVI from now on”.

5.2 Competing regimes of expertise on how to do TAVI: expertise as economically invested and proprietary

In the case of TAVI the flurry of professional and academic visits and exchanges described above coexisted with a different regime of circulation generated by the economic forces which operate in the landscape. The two largest producers of valves had in fact instituted two proprietary networks, which generated competing and alternative circuits of knowledge. These in turn were the result of the intentional and interested effort of the two companies who were set to make very sizable profits from the advancement of this type of intervention and from the control of the expertise associated with it (each valve costs nearly \$20000 each).

Consider how the expertise of doing TAVI was acquired. Valve producers did not simply sell valves and insertion kits. According to our informants, after choosing which provider you would like to work with, your whole team had to travel to their European headquarters to undergo a training program and learn the ropes of TAVI. Here you would acquire the necessary basic skills to perform TAVI in a safe and efficient way. You will also learn more about aspects such as the coordination of the TAVI activities, how to organize the TAVI team, the division of labor between the different team members in the operating room, the setup of the room and so forth according to the company views. Your first local TAVI procedures must be done under the close supervision of one of the company proctors. A

company representative will be your contact person who will occasionally attend to see that everything goes according to plan. The same or different proctors from the company will continue to visit the site intermittently, often when a new model of the valve is introduced. In occasion of these visits, before, during and after the procedures, as well as during other initiatives organized by the technology manufacturer, you would exchange information about other practitioners, practices, tricks of the trade and the current situation in the TAVI market. In short, hospitals were de facto enrolled in ‘closed’ networks that vendors created with and for their clients. These closed networks are the result of the combined work of human intermediaries (proctors) and material mediators (articles, videos, reports). They establish durable relationships between TAVI performing centres and in the process they create and extend particular regimes of expertise which promote and sell trans catheter heart valves of one type rather than another.

5.3 When expertise becomes economically invested and proprietary: some implications

The existence of competing proprietary circuits of knowledge affected all the aspects of expertise discussed above. The firms attended to, structured and facilitated individual learning and expertise refinement. To avoid costly errors (and adverse consequences for patients) doctors could only learn the practice of TAVI at the vendor training centres or under the supervision of one of their proctors. The learning by doing model was still used, but under controlled circumstances and using criteria developed by the company, not the community (for example who would be entitled to be a TAVI novice; how many TAVI procedures you need to become an expert) etc. The proctors (the “TAVI masters”) in turn were not chosen by the community of practice on the basis of professional reputation alone. As one of the informants explained “...the proctors are approved by management within [the valve seller]

and they decided who is suitable...” This is because proctors, who are paid to teach, are not only translators of expertise, they are also builders of networks and enrolling machines. As one of our informants explained “...becoming a proctor enables you to also build a large scientific network” and to include others in it. In summary, the vendors organised their own proprietary communities of practice that overlapped with the existing academic and professional networks.

Relational expertise was also affected. The two vendors developed different technologies and artefacts that require different types of teams, different combinations of practitioners and different number of people in the room (this was one of the “competitive advantages that one of the main vendors claimed to have on the other, although over time the differences tend to fade away). Importantly, at least in the early stages of doing TAVI, the composition of the teams and the way of working together was prescribed by the vendors, who required team training as a conditions for hospitals to become TAVI centres.

Finally, the two vendors, who invested significantly in their own Research & Development, organised they proprietary ways to feedback the experience of users to the designers of new products. They did so by instituting proprietary networks of practitioners. As one of our informants explain:

“Once a year we organise a Nordic TAVI meeting. It is based on experience. We ask the physicians to bring in cases. Cases with problems. Often they say that they like these kinds of meetings. At the big conferences they only present the success stories. In these local meetings they also show what went wrong. It is about 50-60 cardiologist-surgeons. We only invite TAVI [name of the vendor] teams.” [*Interview with vendor representative*].

These nexuses of relationships, which also helped the manufacturers to refine their products and compete with each other, in time, came to constitute alternative and competing

regimes of expertise interested in promoting TAVI and themselves. These economically driven circuits of knowledge co-existed side-by-side, and at times substituted or conflicted with the traditional scientific mode of circulation of expertise. To some extent, expertise was privatized. Vendor did not limit to sponsor conferences and visits. They took control of the whole process.

The existence of such economic epistemic regimes of knowledge circulation and networks introduces a further element of complexity in the understanding of expertise. It also affects the traditional conditions of acquisition, transmission and expansion of the expertise. Both the individual and the group level the acquisition and development of expertise depends upon the positioning in the political economy of knowledge that rotates around TAVI. As we were told in one of our interviews *“To start up a new [TAVI] centre is about 1 million. This includes education and proctoring. Not all centres can afford to do this”* [interview with doctor]. The traditional process of learning by doing may also be affected, as access to learning is now controlled by vendors and limited to hospitals that can fit the required economic profile. Individual motivation and desire to learn may not be enough: chose the wrong bandwagon and you may be starved of connections, support and your knowledgeability may become limited. Moreover, given that large and rich Centres of excellence are more likely to attract the interest of vendors than smaller, peripheral establishment, the process risks to be self-fulfilling and to perpetuate a form of intellectual capitalism (those who have intellectual capital get more of it; the others are increasingly marginalised). The new arrangement also prevents potentially generative knowledge exchanges that can lead to innovation. The connections between centre is now partially affected by vendors who established preferential relationships based on belonging to the same company network. Finally the feedback from users goes back to the firm rather than been made available to the whole community.

In summary, chose not to participate in the system that generates large profits (a 2016 report estimates that the TAVI market will be worth \$5.9 billion by 2022) and the expertise of TAVI will be at least partially precluded to you.

The effects of this partial privatization of expertise of course are not all negative. The competition between the two vendors and the control over the process allowed to speed up the generation of expertise around TAVI when compared with other similar forms of expertise. Mechanisms like proctoring also reduced the number of failures in the learning by doing process. This translated in less problems for patients and better clinical outcome faster. Moreover the circuits of knowledge created by the two firms co-exist, rather replace the traditional academic practices. In short what we describe as the partial privatization of the expertise of TAVI created new opportunities for acquiring and refining expertise as well as new boundaries and potential lines of fracture. In both cases, however, the nature and dynamics of expert knowing were significantly affected and altered.

6 Discussion and conclusion: the rhizomatic and invested landscape of TAVI expertise

In this paper we argued that the case of TAVI prompts us to further expand the idea that medical expertise is personal and social, relational and material. Our suggestion is that this view needs to include the notion that experts are not so much owners of expertise but rather the carriers or conduits of broader circuits of knowledge. Understanding expertise in general, and the expertise of TAVI, in particular, requires to take into account the processes through which knowledge circulates and the different ways in which experts learn to participate in this complex dynamic of circulation. This includes paying attention to the establishment of

closed, proprietary and potentially competing circuits of knowledge. The establishment of such “for profit” epistemic communities adds a further dimension of complexity in understanding of the dynamics of expertise. In modern medicine as elsewhere the nature of expertise, its circulation and the making of money cannot be studied in isolation.

The case of TAVI invites us first to problematize the traditional way in which we ascribe expertise to distributed entities. As we discussed above, expertise is usually attributed to individuals, groups/communities or networks. In the case of individual groups and communities the focus is on the site and the local processes of learning. In the case of network, the focus is on the relationships, while the nodes and their individual history tend to disappear. In the case of TAVI, however, neither approach is satisfactory. Based on our study, in response to the question “where is the expertise of TAVI” we can only point at a rhizomatic set of social and material relationships that as a whole can be ascribed with expertise. Individual, groups and local sites become carriers and developers of this expertise that however they do not “own”. The expertise of TAVI is thus both local and translocal; it “resides” in the relationship between the two. With this we mean that the fluid and evolving expertise of how to perform TAVI is firstly distributed locally among the elements which compose the situated activity system (Engeström and Middleton, 1996; Greig et al., 2012). Expertise is, therefore, eminently territorialised in specific sites. In each site, knowing how to do TAVI well is the result of a history of joint learning, technological choices, or relationships with the larger material context. translocalThis makes each site unique and it is for this reason that you can be an expert in one centre and when operating with one team but you can no longer be an expert when such conditions change.

At the same time, expertise is also distributed among a host of interconnected centres. It circulates among them thanks to the active work of material and human intermediaries, propelled by curiosity, intellectual and material interests. The expertise of TAVI, therefore,

emerges as a property of the connections within and between these nodes. Expertise is both local and translocal and there is no opposition between the two - although tension is always there. We contrast this view for example with the idea of “networks of practice” understood as informal, emergent and often virtual social networks between individuals with practice-related goals which come together to invent and share knowledge (see, e.g., Pugh and Prusak, 2013). In this view the relevance of the local socialization and situated learning processes, as well as the joint history of learning are lost. A rhizomatic view holds fast to the idea that expertise is learned and experienced locally and to the idea that novices can be socialised only if they participate actively in a local culture of practice (an aspect that clearly emerges from our study). It adds, however, that the locality itself depends on what happens in other localities. Indeed, certain sites are better at doing TAVI than others and in our study we heard stories of competition for who is the best. And yet at any moment in time expertise is an effect produced by and emerging from the entire rhizome, rather than from only one of its parts. The adaptive work to advance the expertise of TAVI is performed by the entire rhizomatic heterogeneous entity composed by practitioners, sites and their connections.

One of our main reasons to use the image of the rhizome rather than the more polished idea of network (Hakkarainen et al., 2004; Pugh and Prusak, 2013) or landscape (Wenger-Trayner et al., 2014) is that we want to emphasise that the expertise of performing TAVI is not homogenously distributed like dust on a surface. Understanding expertise necessarily requires also the consideration of how material interests intersect, sustain and hamper the circulation of knowledge and the generation of expertise. The case of TAVI and the presence of (at least) two proprietary networks of practitioners also suggests that modes of circulation based on personal connections and belonging to the same discipline co-exist with those deriving from being part of the same commercial alliance. Accordingly, the circulation of knowledge is not a process of diffusion; equally it is neither homogeneous or consensual or

egalitarian. To become and remain an expert, one has to learn how to navigate in a diverse, unequal and shifting landscape where economic alliances determine access to knowledge sources and where expertise, prestige and money are inextricably entangled. Networks of expertise and circuits of knowledge are not flat -- not in the world of medicine anyway. To the extent that the expertise of TAVI become entangled with profit making considering these economic aspects as external to the study of expertise is rather disingenuous. Economic processes are in fact likely to significantly affect the dynamics of expertise, and how we understand it. On the one hand, as we mentioned above, the introduction of private circuits of innovation introduces new types of epistemic boundaries and potentially interferes with, or renders more difficult, traditional forms of individual learning and mutual exchange. At the same time, the emergence of proprietary circuits of knowledge in competition with each other may speed up the expansion and increase of expertise by rationalising development processes that historically have left to emergent processes.

The case of TAVI of course is particular in that we are observing an expertise still in development. Whether the observed intense rhizomatic regime of circulation and competition will continue or will subside when the approach becomes mainstream is an empirical rather than a theoretical question. What is clear, however, is that the case of TAVI may not be an exception. The introduction of game changing technologies has, in fact, become the norm not only in certain segments of the healthcare sectors in rich countries but also in many other sectors. The solitary master who thrives in isolation is simply not what we found by studying leading edge healthcare practices. Maybe this form of expertise still applies to occupations such as chess master and musicians (two typical cases studies by scholars of expertise: see Hoffman, 1996) but as TAVI suggests this is less and less the case.

Equally, we are not arguing that all expertise is rhizomatic. Several of the observations in our study are linked to the complex, collective and technological nature of TAVI. Our

study, therefore, raise the question on whether expertise can be studied by extending the same categories to large and differentiated sets of phenomena and paves the way for a more nuanced approach that differentiates expertise on the basis of the nature of the practice at hand. In this sense, our radical take on the nature of expertise point at several opportunities for future research: how is the multiplicity of the field reflected and lived at individual level (an aspect that the “unitary” fluency model tends to ignore)? What are the effects of the partial privatization of expertise? What are the skills that allow one to become and remain knowledgeable of the existing and mutable landscape? Is the expertise to connect sites and to deal with vendors similar or different from the already identified forms? Can this expertise in connectivity and commercial negotiation be subsumed under the category of contributory expertise as for Collins and Evans (2008)? Or is there a new form of expertise involved?

7 References

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