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Understanding The Needs of Mentoring in Surgery to Guide the Design of Surgical Telementoring Systems

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All along their careers, surgeons learn through mentoring, operating on patients side-by-side with expert surgeons. However, access to experts is more and more challenging as they are often located far from learners. Telementoring can increase the reach of mentors by supporting mentoring at a distance, but despite their potential, current systems remain rarely institutionalized. We investigate current surgical mentoring practices, to inform future design of telementoring systems in providing support for learning. In a field study, we observe 11 surgeries and conduct follow-up self-confrontation interviews with mentor-mentee pairs. Through Thematic Analysis, we find that the domain of surgery results in mentee's needs for reassurance regarding safety, being spared from workload and risk, both essential to support the acquisition of skills. Second, that mentors understand the situation primarily through the surgical site view but also through inspecting the mentee's posture and the patient's body. Thirdly, that mentors take physical distance as their presence limits mentees' autonomy development. We discuss the limits of current surgical telementoring systems and rethink their role as companions of onsite mentoring.

CCS Concepts: • **Human-centered computing** → *Empirical studies in HCI*.

Additional Key Words and Phrases: surgery; mentoring; mentee; learning; telementoring

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1 INTRODUCTION

Performing surgery requires mastering a diverse and vast set of skills [26], both technical (e.g., instruments, anatomy, establishing a surgical plan) and non-technical (e.g., risk management, decision-making or teamwork). Surgeons acquire much of their knowledge through situated learning in what is known as *mentoring*: young surgeons assume the role of mentees, acquiring and perfecting skills by observing surgical interventions and progressively increasing their participation under supervision of expert surgeons—their mentors. After graduation, surgeons continue learning through mentoring, to update their skills as new instruments and techniques are regularly introduced. However, experts are not always available to regularly travel to the mentees' hospital. This challenge and the need for continuous retraining urge for the development of new systems.

Surgical telementoring is defined as a relationship facilitated by telecommunication technology in which a mentor surgeon provides guidance to the mentee, a less-experienced learner, from a remote location [43]. Telementoring systems typically consist of videoconferencing systems, transmitting audio and video, with the added possibility for telestration on the view of the surgical site, for instance to draw a line that indicates where to perform an incision [2]. This is the case of the commercial system VisitOR1® (Karl Storz; Tuttlingen, Germany). Despite their potential, telementoring is still rarely institutionalized, partly due to safety, legal, financial and organizational obstacles [27], but also because existing systems remain general-purpose, without functions that address specific telementoring needs during physical, tasks such as surgery. Previous works in HCI and CSCW have explored collaborative systems for onsite and remote mentoring, with a focus on deictic instructions through gesturing tools that enable pointing and annotating. These studies showed the benefit of remote pointers to improve surgical work, guide mentees' gaze, increase quality of instructions [17, 18, 45], while drawing attention on how pointers can make communication imbalanced when only the mentor can access them [16]. However, research has not yet demonstrated that telementoring systems provide the necessary tools for mentors to teach new skills [1], the underlying goal of mentoring. Building those tools requires understanding the dynamics of onsite mentoring that support the development of new skills. Works on surgical learning already provide insights on mentoring techniques such as physical demonstrations and verbal feedback [8, 15], however, in order to adequately provide this support, it is crucial for mentors to diagnose mentees' needs as emphasized by the field of educational sciences, for instance through scaffolding [56].

In this work, we investigate practices of collocated mentoring, more specifically, the following questions. First, what are the cues that mentees exhibit and mentors perceive that inform mentors' action? Second, how do mentees benefit from the mentor's presence? We did not observe situated use of telementoring systems, as this practice has been institutionalized in very rare cases, making it difficult to access. Instead, we observed onsite mentoring as typically performed today, to gain understanding of this practice, and thus put in perspective the functions of telementoring tools. We conducted a field study where we observed 11 soft-tissue surgeries in the specialties of gynecology and urology, performed through a variety of techniques (open surgery, classic minimally-invasive surgery, and robotic surgery) to grasp mentoring practices in settings that impose different mentor-mentee configurations and needs. We performed semi-structured interviews with self-confrontation, both with the mentor and the mentee, exploring the causes of communicative acts and mentors' taking over, mentors' perception of mentees and how mentees benefited from mentors' presence. Through Thematic Analysis [5], we shed light on how the highly technical nature and risks of surgery impact mentoring practices. We first find that, when learning, mentees need to identify and fill their gap in expertise, share workload and risks, and be reassured. Those needs are met by mentors through external guidance, takeovers and simply by being present. Second, mentors

understand these needs and risks primarily through observing the surgical site as well as through inspecting mentees' posture and the patient's body. Third, we show that while the presence of mentors plays an important role in providing reassurance on safety and sparing from struggles, it limits the development of autonomy.

This study contributes to the future design and use of collaborative systems for remote mentoring in two ways. First, we discuss the limits of current systems most notably the fact that they constrain vision, they limit implicit validation and that mentors cannot understand and fulfill mentees' needs to the same extent as when they can directly act on the body. Second, we rethink the role of telementoring systems as companions of onsite mentoring, rather than systems that reproduce and replace collocated mentoring.

2 BACKGROUND: THE COMPLEXITY OF SURGERY

Performing surgery requires mastering many different skills, both technical and non technical. Some of these skills include identifying anatomy, motor skills, making sense of haptic and visual cues, adapting strategies to particular situations, team work, attitudes and behaviors [14]. Numerous skills are then combined to perform complex tasks, such as dissection, which consists of progressively separating structures to create a surgical plane through detaching surrounding tissues, or exposition, which consists of creating a relevant view of the surgical site through adjusting the camera as well as hauling and pushing structures. Through dissection and exposition, surgeons discipline the body, a process that seems to “disfigure” tissues to the untrained eye, but actually exposes and *creates* the body to the expert surgeon [25, 39].

In addition, different surgical techniques exist, such as open, laparoscopic, and robotic surgery, each one requiring adaptation of the acquired skills. Open surgery involves operating directly through a large incision, where surgeons manipulate and see the body directly. In minimally-invasive surgery, instead of a large incision, surgery takes place through small holes called trocars, where elongated surgical instruments and a camera called endoscope are inserted. The surgeon manipulates the tools while observing the interior of the body through a monitor (Figure 1). Lastly, robotic surgery is a type of minimally-invasive surgery where the surgeon sits at a console where they see the body through an immersive 3D screen, and manipulate non-sterile joysticks to control robotic tools inserted into the patient. These techniques have differences and similarities. For one, in both open and classic minimally-invasive surgery, surgeons work in pairs, where one manipulates tools to perform actions on the body (e.g., cut or dissect tissue), while the other drives the endoscope and manipulates organs to perform exposition. However, in robotic surgery, one surgeon is in control of all the instruments needed to perform gestures. Here, the role of the assistant focuses on handling the robotic equipment [3]. Another difference is vision, as in robotic surgery the surgeon immerses their vision in a stereoscopic view of the endoscopic video, giving them access only to the surgical site. In contrast, in open and classic minimally-invasive surgery, surgeons can direct their view toward the surgical site, as well as other team members by just looking around. All in all, surgery is a complex activity where expert knowledge is tacit and hard to formalize [40]. Therefore, much of the learning in surgery happens through practice under the supervision of experts.



Fig. 1. A mentor and a mentee operating

3 RELATED WORK

3.1 Learning Through Apprenticeship

The journey to becoming a surgeon starts with acquiring theoretical knowledge on anatomy, procedures and techniques. Then, medical students weave in practice [21] and develop skills through apprenticeship, becoming mentees that operate under a mentor's expert supervision. Prentice [40] defines this practice as *guided physical training*, or *guided practice*, where the trainee directly observes and then imitates the actions of a skilled mentor. Thus, learning happens through situated action, occurring in the context of particular and concrete circumstances [51]. We now review theories in social and educational sciences on mentoring and present studies that use these theories in surgery, to detail three characteristics of apprenticeship through which mentors adjust how they transmit knowledge, to the current situation: adapting the amount of support and difficulty, adapting the strategy, and diagnosing the mentee.

3.1.1 Adapting the Amount of Support and the Level of Difficulty. Mentors adapt the amount of support during apprenticeship, gradually increasing the level of difficulty in the tasks they propose to mentees and reducing assistance. This phenomenon was first described in Vygotsky's Zone of Proximal Development (ZPD) theory [57], which states that learning is most efficient when mentors present tasks that surpass the learner's independent problem-solving abilities (zone of actual development), but remain achievable with guidance (zone of proximal development). The assistance experts provide is contingent on and responsive to the learner's level of performance [15]. Although the ZPD highlights the need to adjust the level of difficulty, it does not describe how mentors adapt and gradually remove their support. This is detailed in the theory of scaffolding [6], which emphasizes how mentors act as temporary support toward the completion of a task that mentees cannot perform alone, analogous to a scaffold aiding in the construction of buildings. There are three key characteristics to scaffolding [56]: *contingency*, as mentors tailor support in response to mentees' needs; *fading*, as they gradually reduce support; and *transfer of responsibility*, as they aim at eventually departing. Lastly, cognitive apprenticeship theory [13] establishes that mentors need to create sequences of activities where tasks increase in complexity and diversity, to favor the integration and generalization of knowledge and complex skills.

Specifically in surgery, Prentice [40] observed how mentors adapt support and difficulty by challenging the mentee with tasks toward their zone of proximal development. The case involves a surgeon pushing the learner's boundaries by directing them to operate a drill using the left hand when inserting a screw into the bone, something that made the right-handed mentee anxious, but constitutes an important skill for future situations. While the mentee felt unprepared, the mentor provided temporary support through guiding the learner's hands, adding counter pressure to make sure the drill did not fail.

3.1.2 Adapting the Strategy. Besides adapting the amount of support, mentors also adapt their strategy. The theory of cognitive apprenticeship [13] and scaffolding [56] outline several strategies: *modeling*, performing a task for the mentee to observe; *coaching*, observing and facilitating; *scaffolding*, actively supporting the mentee by accomplishing parts of the task; *articulation*, encouraging to verbalize knowledge and thinking; *reflection*, enabling the mentee to compare their performance; and, *exploration*, inviting the student to pose and solve their own problems.

Specifically in surgery, one study documents the use of modeling, feedback and videos for mentoring [15]. Authors highlight that modeling was the dominant method as hand gestures are usually taught by demonstration, and that verbal feedback was a means to communicate quality standards through explicating accepted levels of both positive and negative outcomes, which should be realistic because unrealistic benchmarks can discourage mentees and lead to anxiety. Moreover,

mentees' preference on the strategy depends on their experience: modeling and coaching are adequate for junior residents, and exploration and articulation for senior residents [37]. Besides supporting mentees *during* the operation, mentors can also provide coaching, articulation, and reflection *after* surgery, reviewing videos of mentees' performance [8].

3.1.3 Diagnosing Mentees' Needs. To adapt support and strategies, mentors aim at understanding mentees' needs through diagnosing strategies [56], which are not thoroughly documented in the literature, especially in surgery. Feng and Mentis [19] acknowledge that mentors assess the resident's level of knowledge to gauge the amount of guidance provided during a specific procedure. This work shows three ways in which mentors discern the information needs of mentees. First, when mentees express verbal requests such as checking their own understanding, querying to elicit new information, or asking for confirmation on their decisions. Second, by relying on the existing mutual understanding between the pair. Third, by observing and interpreting mentees' actions. However, as mentees assume that mentors check if their actions are coherent with the given instructions, mentors sometimes lack feedback and need to make sure mentees understood correctly the information they have just given through verbal utterances [19, 20]. Instructions in surgery need contextual understanding, as Mondada notes, instructions are "*inescapably indexical, incomplete and allusive*" [36], and their intelligibility relies on the understanding of the procedure, as well as the skills and competence of the assistant. In other words, the surgeon evaluates the assistants' level of knowledge and adapts their strategy for easing its skilled interpretation.

To conclude, social science theories on apprenticeship posit that mentors adapt their support, the task difficulty, and the method. Although we know that they seek information on mentee's needs, it remains unclear how they do so, and thus how a particular context influences their decision on a particular strategy. This understanding is key to evaluate if current tementoring systems (1) support mentors in diagnosing the situation and triggering a specific form of support, and (2) provide remote support that answers mentees' needs, rather than reproducing onsite mentoring.

3.2 Technological Support for Onsite and Remote Surgical Mentoring

Research in HCI and CSCW have studied the use of collaborative systems to support surgical mentoring, both remotely and in onsite settings. Through our review, we highlight the lack of understanding concerning the limitations of those systems in relation to mentoring needs.

3.2.1 Supporting Onsite Mentoring. Works in onsite settings can inform the design and use of tementoring: they highlight mentoring needs that tementoring systems would also need to support as well as propose new tools that could also be integrated in remote scenarios. Systems for supporting onsite mentoring have focused on communication issues when using imaging systems—systems that display preoperative images of patients. These systems have been shown to support the development of common ground [20], but also affect work practices by creating the need for additional articulation work [30]. The use of virtual pointers in imaging systems, controlled through mid-air hand gestures, has been shown to support the adoption of professional vision [18] (i.e., the pointer supports the mentor in teaching how to interpret the image), and to guide the mentee's gaze thus increasing quality of instruction [16]. Still, pointers implemented as single-user tools, where only the mentor produces input, can actually induce a cost in communication, as they can make communication imbalanced and make mentees less active [16], which translates to reduced contributions and passive learning.

3.2.2 Supporting Telementoring. Studies of technology used for telementoring have focused on telestration as well as the feasibility of Virtual and Augmented Reality (VR & AR). Mentis et al. [32] studied the remote use of imaging systems during organ transplants, where the collecting surgeon uses video captured through an HMD to craft a view for the remote surgeon, with the goal of facilitating the co-construction of knowledge and shared decision-making. The use of telestration has been shown to reduce the total duration of mentors' intervention by 30% [7], and to further support practices for remotely shaping the view [31]. The social challenges of virtual pointers have also been studied in remote settings, showing that they are interpreted as the main source of information and thus can create confusion when their use is not aligned with verbal instructions, and, that a single pointer is insufficient for complex manipulations, all of which impact learning [45]. Surprisingly, the fact that a virtual pointer is remote, can actually change behavior and lead trainees to attend more to the instructions, leading to a higher perceived quality of instruction [46]. All in all, virtual pointers are sociotechnical systems, where their success relies on both technological design and their situated use in a social context, which may require training the mentor to use pointers [47].

In the context of open surgery, VR & AR have been explored to overlay remote annotations onto the patient body, the surgeon's focus of visual attention, instead of doing so on a separate display. The ARTEMIS [24] research prototype augments the operating room, displaying the remote mentor's body and annotations through AR, and creating an immersive environment of the operating room through VR on the remote mentor side. That way, the remote surgeon can create localized annotations on the patient to support instruction, and show gestures that the surgeon needs to perform. This is typically because the view is mobile, annotating requires freezing the view, although recently Seo et al. [48] proposed the use of an actionpad to annotate on live mobile views. Although these works point to limitations in terms of vision and annotation precision, as well as the potential of sharing the mentees' exact perspective, they do not explore how the setup can support diagnosing the mentee's needs despite their potential to convey remote contextual information.

In summary, the study of onsite and remote technology for mentoring provide insights on how different tools contribute to different aspects of collaboration (e.g., common ground, co-construction of meaning, communication), instruction (e.g., perceived quality and attention, time) and skill development (e.g., professional vision). However, the current understanding of mentoring dynamics is limited, hindering the identification of other aspects where technology could be used to support the mentoring and learning process.

4 METHOD

This work is an empirical study of onsite mentoring practices, consisting of surgery observations and semi-structured interviews with self-confrontation [34, 54]. During each surgery, a mentor supervised a mentee while they operated, with the goal of transmitting expertise. We chose to observe mentees that are, or about to become, attending surgeons. We target this population to understand mentoring dynamics that involve transmitting surgical skills to surgeons that can already perform some surgeries autonomously. Remotely mentoring younger medical students that cannot handle a minimum level of risk independently does not constitute a realistic use case for telementoring. We obtained ethics committee approval for this study from our University IRB. Following our commitment of transparency research, we decided to register this study to establish the motivation, research questions and planned analysis. The preregistration of this study can be found on the platform OSF (Open Science Framework) following this link: <https://osf.io/epjwg>.

4.1 Participants

Ten surgeons participated in this study, throughout 11 surgeries. [Table 1](#) shows how they contribute to the data for this study. Participants 1 to 4 are attending surgeons in their first years of practice, enrolled in a mentorship program with senior surgeons. They operate independently for some surgeries, and under mentor supervision during complex cases. Participant 5 is a senior resident, we include them in

Surgery	Type	Speciality	Mentee	Mentor
S1	robotic	urology	P4	P10
S2	open	gynecology	P2	P6
S3	open	gynecology	P1	P8
S4	robotic	urology	P3	P10
S5	robotic	gynecology	P7	P8
S6	laparoscopic	gynecology	P2	P6
S8	robotic	gynecology	P1	P6
S7	open + lap.	gynecology	P8	P7 (colleague)
S9	open	gynecology	P6	P9
S10	robotic	gynecology	P5	P8
S11	open + lap.	gynecology	P7	P8 (colleague)

Table 1. Participants and their roles in the observed surgeries.

the study as they were about to become an attending surgeon. Participants 6 to 10 are senior surgeons. Still, P6 and P7 took the role of mentees once: P6 was a senior gynecologist surgeon mentored by a digestive surgeon to learn digestive gestures, and P7 was mentored to update their skills with the latest recommendations using new equipment. In S7 and S11, both P7 and P8 were operating autonomously on a patient after having both observed an expert perform a new technique in a different institution, and having trained on a simulator. We acknowledge that the dynamic of this surgery is different from standard mentoring, as here the responsibility bears firstly on the operating surgeon, while in typical mentoring the mentor is always responsible for the outcome of the surgery, even when the mentee operates. We nonetheless included this surgery in our study for three reasons: the helping colleague takes the role of a mentor providing advice, the situation closely resembles telementoring in the sense that takeovers are less frequent (there is more focus on advising compared to reproducing), and, this type of situation could be a use case for telementoring, as the surgeons we observed previously traveled to a different city to learn a new technique as a mentee.

The 11 observed surgeries included different techniques (open, classic minimally-invasive and robotic surgery) and specialities (gynecology and urology). These two specialities deal with soft and deformable organs, and therefore require learning similar tasks (e.g., cutting tissue, identifying anatomy, or feeling the stiffness of tissue). We choose to observe different techniques in order to encounter diverse approaches to collaboration and learning, as communication varies depending on the medium and their associated constraints [11]. Each week, we contacted each surgeon to plan the observations according to the following criteria: planned presence of the mentor, and planned participation of the mentee, such that this surgeon is able to operate for most parts as opposed to only observing or assisting the mentor.

4.2 Data Collection

4.2.1 Surgery Observations. For each observation, we collected both audiovisual data as well as field notes. **Video and Audio:** we recorded video and audio using a hand-held camera for open and laparoscopic surgery to capture the surgeons and the surgical site view. For robotic surgery, we used a fixed camera and additionally recorded the endoscopic video. **Field Notes:** During observations, we noted down moments where mentors took over, looked at each other, or provided verbal or gestural instructions either with their hands or the robotic platform pointer. We subsequently extracted snippets of the videos starting around 30 seconds before the takeover or instructions occurred. We used those videos for interrogating participants during interviews.

4.2.2 Semi-Structured Interviews with Self Confrontation. We interviewed both the mentors and the mentees separately as soon as possible after the observation. Depending on surgeons' availability, this ranged from a day to four weeks. **Audio:** We recorded the audio of interviews for later analysis. Sessions consisted of three parts. In the first part, we brought the participant to the general context of the surgery. Second, we proceeded to self-confrontation [34, 54], where we showed video snippets of their own practice to ground responses on specific moments. This technique resembles video-cued recall debrief [4] with the difference that the video was not first-person view, as wearing a head-mounted camera was a nuisance to surgeons. Through the use of videos, we aim at benefiting from similar advantages to video recall, namely to generate more recollections compared to free recall, and access what participants thought and felt. For each video snippet, the interviewer put the interviewee in a reenactment position, as opposed to a fabrication or self-judging position. Afterwards, the interviewer showed the snippet and elicited responses on a number of questions, asking the participant, either mentor or mentee, what their thoughts and feelings were. Specifically for mentors, we asked the reasons for their actions, for example taking over, verbal expressions or gestures, how they acquired the information that guided their actions, and their general perception of the mentee. Regarding mentees, we asked what led them to communicate intentionally, and how they benefited from the mentor. As we had limited time to debrief the situations, we skipped the events that did not evoke particular thoughts or memories or were repetitive with previously shown video snippets. We also prioritize debriefing events that we considered the most different events already discussed. For instance, we prioritize debriefing a gestural instruction over a quick pointing gesture, which occurs frequently. The third part consisted of a semi-structured interview to inquire further potential moments where communication could have been improved and where help was particularly needed, as well as how the overall learning experience was perceived. The interview guide with the specific questions is available in [Appendix A](#).

4.3 Data Analysis

We performed a Thematic Analysis [5] using the audio recordings of interviews. We listened to the recordings and coded verbal speech, generating time-stamped codes. Then, we revised the codes and reformulated the wording to disambiguate the code meaning. We then transcribed portions of the interviews to use as quotes. We did not perform full transcriptions because self-confrontation interviews, contrary to semi-directive or directive interviews, led to recall and sharing of rich details that were not relevant to our research questions and thus unnecessary to transcribe and analyze, from our perspective. We re-listened to the interviews as necessary when generating themes from codes, which helped us grasp context, hesitations, or confidence with which the interviewee made their statements. Our epistemological stance leans toward constructivism, thus, we conducted an inductive analysis. The first author coded data and constructed themes, involving one expert surgeon at various times to co-construct meaning, but also for the purpose of member checking.

5 LIMITATIONS

Our study includes a limited population: 10 surgeons, where 8 of them took the role of mentees, and 5 of them the role of mentors. Our results are not based on existing telementoring between institutions, which leads to particular behaviors. First, the responsibility of the surgery institutionally lies on the mentor's shoulders which inevitably pushes them to be more present and guiding, whereas we suppose that externally-invited experts would be more likely to suggest instead of direct. Second, although we observed graduated surgeons, most of them were still in the beginning of their career, and more importantly, not autonomous in all observed surgeries. The fact that we observed onsite mentoring and not telementoring systems, means we cannot make claims regarding the implications of such tools, only about the needs they should address in their design. Additionally, we interviewed

surgeons sometimes four weeks after the surgery which made it difficult for them to reenact certain situations. Regarding the self-confrontation interviews, we acknowledge that selecting moments in the surgery is a bias, as we more easily notice the more salient interactions such as louder verbal interactions, bigger gestures, or taking over. In particular, it was difficult to notice moderate and smaller gestures in open surgery. Lastly, we observed surgery where the provision of help to mentees was planned.

6 RESULTS

Throughout our inquiry of surgical mentoring, we show how the context of surgery leads to additional needs beyond acquiring technical expertise, resulting from the length of surgical procedures, the need for diverse skills to perform action, and the high stakes involved. We observe that, first, mentors understand mentees' needs and risks primarily through observing the surgical site, but also through inspecting mentees' posture and the patient's body. Second, that mentees benefit not only from mentors providing expertise or sparing them in times of struggle, but also from mentors' reassurance. Third, that mentors take physical distance as their presence limits the development of autonomy. When presenting quotes, we include the participant id, the capacity in which they participated in the surgery (mentor, mentee or colleague with a similar level of expertise), and the surgery where the event took place.

6.1 The Needs Beyond Acquiring Technical Skills: to Be Spared and Reassured

While learning new skills is the end goal of mentoring, mentees' needs are not limited to acquiring expertise. These additional needs involve creating favorable conditions for learning to take place, including the need for mentors to take charge, and perform parts of the surgery when the difficulty or risks are too high, as well as the need to be reassured on the patient's safety along the operation.

6.1.1 Need to Identify and Fill Gaps in Expertise. Both mentors and mentees stated that mentors help mentees to overcome obstacles, mitigate struggles, gain in efficiency, and increase safety. While the sheer act of observing mentors perform surgery can lead to learning, mentees mentioned repeatedly being interested in performing surgery themselves, as they already had observed many surgeries before. Beyond observing the optimal strategy or gesture, mentees want first to identify the limitations of their own knowledge, before taking advantage of mentors' expertise. Therefore, it is not only the content of an instruction that contributes to its value, but also the moment when the instruction is given, in particular, after a mentee faces the limits of their own skills. P8_{mentor} and P5_{mentee-S10} emphasized the need for mentees to confront themselves with the "technical block" (P8_{mentor-S5}), in order to improve their skills. P4_{mentee-S1} explains in more detail:

"It is quite important to do, to try for yourself, to be confronted with your own failure more or less, or with your own slowness, your own difficulty in performing the gesture in order to feel the difficulties that you do not necessarily perceive when you watch others do it, or when you are really guided step by step, sometimes you do not necessarily realize the difficulty." (P4_{mentee-S1})

Oftentimes, mentees do not immediately understand they are confronted with difficulty. This is particularly important for safety, because difficulty does not immediately lead to struggling, and thus an increase in risk can be overlooked. Similarly to when mentees are confronted with struggles, mentors help mentees identify the limitations of their approach and contrast it with a better one.

Filling the gap in mentees' expertise can be done verbally or physically. Verbally involves reminding or advising on what should be done, where mentors play the role of an "external eye" (P5 *mentee-S10*), that is, supporting the mentee in understanding the situation. One particular case we repeatedly observed was reminding to perform secondary tasks simultaneously to the primary task. For example, during dissection in S10, the mentor emphasized the importance of coagulating bleeding (secondary), something that the mentee had noticed but not addressed as they were more focused on extracting the uterus (primary). We also observed in S7 how the mentor reminded to push the uterus as a complementary action to dissection, expressing: "I think he had a lot on his mind, maybe he forgot the obvious: pushing the uterus" (P8 *mentor-S11*). Another example is mentors making recommendations to ease a gesture or overcome being stuck, as it was the case in S11 where the mentor's suggestion of swapping tools between hands lead to a less effortful gesture. The second way to fill the knowledge gap is *taking over*, as taking control of the surgery momentarily to model a gesture [15] lets mentors explain complex concepts through performing actions themselves. Here, the goal is not "to replace his [the mentee's] gesture, but just to point out the gesture he should make" (P8 *mentor-S5*). We also observed modeling being used to quickly contrast the mentee's approach to the mentor's: "In fact, I took her hand back because I wanted it to flash for her, the way she was and how I put myself" (P8 *mentor-S10*) as opposed to guiding step by step toward the optimal gesture execution. The action of taking over thus is either to instruct faster or to instruct complex information.

6.1.2 Need to be Spared from Risk, Workload and Difficulty. Mentors spare mentees from parts of the task, both to facilitate the acquisition of expertise in a safe environment and to maintain quality standards. As mentors take on some of the load, they give room for the mentee to focus on what they determine is necessary to learn at the current stage of the mentee's career. This includes mentors taking in charge tasks that mentees have not yet learned, but also tasks mentees are able to perform individually, although with difficulty when performed along other surgical tasks. The transfer of the load can occur at one or more surgical steps or throughout the whole surgery. We identify two strategies for sparing the mentee: taking over (e.g., managing exposition) or guiding action (e.g., making decisions).

Taking Over to Spare From Risk and Workload. First, mentors take over to spare the mentee from risks that they may not yet feel comfortable taking, something that both mentors and mentees mentioned. Certain gestures in surgery require taking risks, given the need to wound important anatomical structures in the process. In these cases, mentors spare the mentee from taking the risk, to create a learning environment where mentees act without the stress involved in risk-taking, but also to bear the full responsibility in case of an undesirable outcome. Indeed, surgeons have a "best endeavors obligation" (P6 *mentor-S8*) which obliges mentors to take over in risky situations with a low level of control "in order to be in the best conditions for the patient" (P1 *mentee-S3*). In this case, mentees still acquire expertise as it constitutes modeling. We observed an interesting exception during S6, where, even if the mentor decided to let the mentee operate at a critical moment that involved risk, she gave very directive instructions to the point that P2 *mentee-S6* considered he was the mentor's "own hands" (P2 *mentee-S6*).

Second, mentors take over to relieve mentees from part of the workload, including performing the operation in a timely manner. Mentors can take over in anticipation of potential fatigue or after fatigue arises, so that the mentee is able to focus later on. Mentors mentioned that in this way, they save the mentee's energy, as managing the entire surgery is more tiring for learners than for experts. For instance, one mentor reported taking in charge the robot installation and the first stage of exploration, to let the mentee focus on dissection. The mentee had a different perception of the cause of takeovers, attributing as a cause the tight schedule of the operating room

which required to speed up the surgery (P1_{mentee-S8}). Another reason mentors take over is to end mentees' struggles when they are stuck. Mentors can perform a step they consider particularly difficult for the mentee, and thus let them rest and regain energy for a subsequent surgical step:

"I took over to relieve him of the psychological and concentration burden so that he could rest a little. Let him continue to see but let him rest. And when we got back to an easy time, I gave him the control back, [...] so that he could go back to a time that was not difficult, so that he could regain his confidence and move forward." (P8_{mentor-S5})

Beside managing mentees' energy, both mentors and mentees recognised that mentors frequently take over to advance in the surgery and respect the operating room schedule as much as possible, to ensure all operations take place without having staff work overtime as well as to limit anesthesia time, as longer operations are linked with post-operation complications [59]. Younger surgeons can take longer time to operate for several reasons, such as fear and repeated verification before making an incision. Also, they may have difficulty finding the right dissection plane and may need more time to explore. Even if mentors can help by validating action to reduce fear and direct more quickly toward the right plane, mentees remain more prudent, operating more slowly as they are responsible for their gestures and want to make sure they will not wound structures by mistake. One mentee for example mentioned that operating faster is not a goal for her, but a result of acquiring expertise. However, ultimately mentors need to take over as they are in charge of keeping the schedule, and *"keep the target in relation to the hospital"* (P10_{mentor-S4}). In this case, the mentor may be taking away the chance to learn by doing, but there can be a valuable lesson on how to keep an acceptable pace in surgery.

Guiding Action to Spare from Difficulty. Mentors do not only spare by performing a gesture in lieu of the mentee, they also spare by guiding action, so that the mentee can focus on performing a well-executed gesture. For example, mentors can perform exposition and provide additional verbal and gestural cues to create a path for the mentee to follow, something referred several times as imaginary *"dotted lines"* (P1_{mentee-S3}; P5_{mentee-S10}).

"Doing the gesture to incise or coagulate is not the most complicated part of surgery. [...] When you start, it is like if you have dotted lines, you were told to cut on the dotted lines. [...] What is complicated is to write the dotted lines. And generally speaking, it is her [mentor] who does it by talking to me. After that, it is to put yourself [at the right angle] when you have to cut. The fact of writing the dotted lines and [...] making sure that your exposition is correct, these are the two steps that I consider to be the most complex in surgery" (P5_{mentee-S10})

Beyond guiding through paths, mentors can also guide other aspects such as the start or end of a gesture or its duration, for example during coagulation. We observed this guiding process occur through different means: a virtual pointer along with verbal instructions in robotic surgery, camera holding and verbal instructions in laparoscopic surgery; and, holding organs and verbal instructions in open surgery.

All in all, the benefits from a mentor's assistance includes being spared from parts of the surgery workload, risk and difficulty, in order to be able to progressively learn new skills.

6.1.3 The Need to Be Reassured. Safety is primordial in surgery given its high stakes. Mentees need to make sure they are in a safe condition in order to learn, otherwise, they might be in a state of fear which is not an appropriate condition for learning. This reassuring aspect was brought up by several mentees as one of the core benefits of having a mentor by their side. We observe two ways in which mentors ensure safe conditions to perform action. First, by the mere act of being available “*just in case*” (P7 *mentee-S5*) there is a need for providing assistance when managing potential accidents or risky situations. Second, by validating mentee’s actions when they face doubts or obstacles, confirming that they are indeed on the correct path. Reassurance is extremely important to alleviate doubts, in particular those “*that are not really rational*” (P4 *mentee-S1*), it helps “*go a little faster in the decision-making*” (P8 *mentor-S11*), and “*to keep you going*” (P2 *mentee-S6*). In cases where mentors share the same doubts as mentees, they validate their prudence, for instance, that they are correct in operating slowly or keeping a margin to avoid the wound of important anatomical structures.

We observe that implicit validation plays a role for reassurance, as the sheer presence of a mentor, when no explicit feedback is provided, validates the mentee’s action and therefore reassures. Throughout the surgery, if the mentor gives no other signal, their presence implicitly validates what is currently happening: “*The absence of report is a communication in itself, it means that it is good.*” (P8 *mentee-S7*). Presence nonetheless can manifest in different ways, as mentors and mentees described during interviews. Some interviewees hinted toward the physical aspect of presence, the act of being in the room, others, hinted toward presence manifested through showing focus on the current task. Mentors show focus through the performing of actions, which need not be complex, such as centering the camera or cleaning its tip when the vision is blurry. Moreover, we observe that the feeling of presence is situated, it varies depending on the surgical setting. For example, in robotic surgery, because the mentee is immersed in the console, they cannot assess presence through sight, as they do not see the mentor. Still, P4 *mentee-S1* reported feeling presence even if the mentor had withdrawn from the console, and thus was not observing the surgery, which they found only moments later. This implicit validation arising from feeling the presence of mentors adds to explicit validation strategies, such as verbal affirmation, pointing at the direction the mentee is going for, confirming the action with a gesture, or simply giving a head nod.

We conclude this section with one last need that P7 mentioned from her experience as a mentee, which precedes the needs presented so far: trusting the mentor. Trust is a key factor for operating alongside a mentor, and is progressively built over time through accumulating experience. Still, P7 explains how they can trust experts without the need to know them as deeply as other colleagues they collaborate with, simply because of the fact they are experts: “*When you do not know something, you trust the expert*” (P7). So far, we have detailed the main needs mentees have to learn, with adequate conditions. These needs vary along the surgery, depending on the task to complete. In the next section, we detail the cues that help mentors identify when these needs emerge.

6.2 Mentors Understand Mentees’ Needs Through the Surgical Site, Postures and Tissues Manipulations

Mentors gather information to identify mentees’ needs through observing the surgical site, the mentee’s posture, as well as through actively performing actions. These results come mostly from the perspective of mentors, regarding how they understand the current situation. [Figure 2](#) summarizes the cues mentors observe, how they contribute to identifying the mentee’s state and the risks, and the needs mentors diagnose.

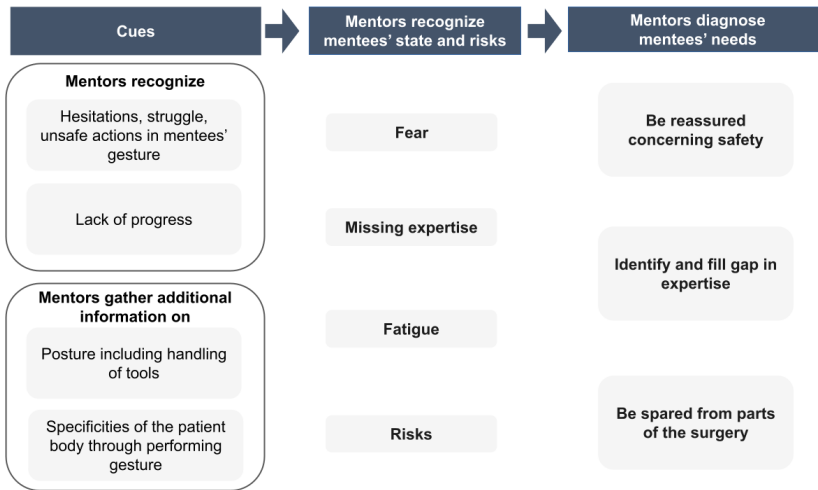


Fig. 2. How mentors diagnose mentees' needs from perceived cues

6.2.1 *Mentors Recognize the Mentees' State and Risks in the Surgical Site.* When looking at the surgical site, mentors recognize hesitation, struggle, lack of progress, and unsafe actions in mentee's gestures. These cues are the primary source of information on mentee's missing expertise, but also on their fear, imminent fatigue and risks. We note that while the information is directly accessible to mentors in minimally-invasive surgery, in open surgery the incision can be small and reduce visibility, in particular it is difficult to see the surgical site at the same time as the mentee, as P8_{mentor} expressed. In these cases, mentors can have difficulty monitoring mentees' action, and thus ask to stop operating so they can place their head in the mentees' head location, to be able to see structures deep down in the surgical site.

Hesitation. We observe that hesitation is identified when mentees challenge their own gestures, something that can have different origins. On the one hand, hesitation can be a consequence of doubts regarding the end goal, which can be exacerbated by fatigue. P8_{mentor-S5} for example described that when hesitating, mentees “grope a little bit, [they] do not know if [they] should cut to the right or to the left” (P8-S5), which makes him wonder about the mentee's intentions and expertise: if the mentee “really knows where he should go” (P8_{mentor-S5}). On the other hand, hesitation can be a consequence of doubts regarding safety. We observed different ways in which mentees manifest hesitation on gesture execution, one is “task interruption” (P8_{mentor-S11}) within a particular operative time when “there is no need to stop” (P8_{mentor-S11}); another is abundant verification (P8_{mentor-S11}), for example moving structures before making an incision, such as the mentee “pushing the uterine” (P8_{mentor-S5}) or “stretching the tissues” (P4_{mentee-S1}). Doubts regarding safety can lead to fear of execution, something that we heard consistently in interviews both on the mentors' interpretation of hesitations and mentees' explanations. Interestingly, P8_{mentor} details how fear is not always due to lacking expertise on technical knowledge, but it can reflect the mentee's lack of ability to assess risks or manage complications.

“He hesitated to go. In fact, he saw where it was, but as we are not very used to it, I think he was afraid to cut. Telling himself, ‘what I need to cut, is it the right place where I do not risk cutting the bladder?’ I understand that he hesitates because I too would have hesitated” (P8_{mentor-S11})

Besides observing the mentee's gestures, mentors rely on context to determine if hesitation arises from missing knowledge about the end goal or from safety concerns. Therefore, depending on contextual elements such as past struggles that the mentee faced, current risk, and knowledge of the mentee's skills, mentors can conclude that the cause of hesitation lies in fatigue or fear of complications. Indeed, P8_{mentor-S5} described that hesitation was a symptom of fatigue after acknowledging that the mentee had been operating for a long time, and on another occasion he acknowledged the risk of the situation was the main source of hesitation.

Struggles. The second observable cue that mentors recognize in gestures is struggles. We observe that struggles result from missing expertise on a more efficient technique to achieve the same result, and can increase risks and the mentee's fatigue. When surgeons do not master a surgical gesture yet, they may follow a suboptimal strategy that in turn leads to unnecessary effort. In particular, suboptimal exposition can make the gesture harder to perform and riskier, therefore more stressful, as the visibility is low. The mentor's support in this case is important as it prevents mentees from wearing themselves out unnecessarily, or, in complex cases, to enable the mentee to overcome the barriers that prevented them from completing the gestures. Here, conversely to hesitations about goals, the problem is not what to do or where to perform action, but rather how to do it differently with relative ease, as P8_{mentor-S5} explains: *"He did not necessarily realize that he was not well exposed [...] He did things but with difficulty. But it [mentor's modeling of exposition technique] was a way of showing that it was easier to do it [another] way"* (P8_{mentor-S5}).

Lack of Progress Across Stages. While struggling applies to the time scale of a gesture, mentees can also face difficulty over longer periods of time. Mentors identify lack of progress by monitoring the mentee's gesture over time, as even if a gesture may not appear hesitant or laborious, it may still be inefficient over time. After allowing the mentee to perform actions, mentors can realize that the mentee is not making *"significant progress"* (P10_{mentor-S4}) in their recent gestures. Nonetheless, surgery needs to constantly move on as P2_{mentee-S6} explains:

"Doing surgery is to keep going. It has to go on, people cannot stay asleep forever. If you do not move forward, that is when things can potentially bleed, when you do not control things" (P2_{mentee-S6})

It is important to monitor progress because, similarly to struggles, it often signals missing expertise on a more efficient strategy, as well as lack of control, which can increase risk, for example from bleeding. Conversely, when mentors see there is *"good progress and [the mentor is] in the relevant plan"*, they *"try to let them continue"* (P10_{mentor-S4}).

Unsafe Actions. Lastly, we observe that mentors pay attention to safety as a quality of gesture execution. Unsafe actions result from missing expertise on how to ensure safety while executing a gesture, something that increases risks. Mentors monitor if the execution of a gesture guarantees safety given the current situation. Unsafe gestures include *"cutting without having a good vision of what [is] cut"* (P6_{mentor-S6}), *"scratching veins"* (P10_{mentor-S4}) or *"not having bipolar forceps ready to coagulate"* (P8_{mentor-S10}).

All in all, mentors can identify gaps in a mentee's expertise, their fear, fatigue and risks, through monitoring the surgical site and recognizing in the mentee's gesture their hesitations, struggles, unsafe actions, as well as paying attention to the progress of each surgical stage. However, we observed that when the information available on the surgical site was not enough to make informed decisions, the mentor actively gathered more information.

6.2.2 Mentors Gather Additional Information on Struggle, Risk and Missing Expertise Outside the Surgical Site View. Although the surgical site typically informs mentors on struggles and risks, it does not always inform on the cause of struggles, and the exact nature of risks in unusual situations. We observe two ways in which mentors actively gather further information to understand the source of these factors. First, they observe posture and tool obstructions outside the body. Second, they perform gestures on the patient body themselves to gain understanding, particularly when the patient body does not look or reacts as expected.

Observing the Mentee's Posture. Mentors examine the mentee's posture, focusing on their relative position to the patient and potential tool blockage to determine the reason behind struggles, after struggles have been identified by observing the surgical site. Posture is important as suboptimal posture leads to tiredness, and therefore mentors monitor "if he [mentee] keeps his shoulders low and his elbows close to the body to become less tired" (P3_{mentor}). Likewise, the positioning of tools and distribution between dominant and non-dominant hand can spare effort, or even facilitate reaching a certain location in the body. In particular, in laparoscopic surgery, mentors need to check the limited range of motion of the tools outside of the patient, as this may be the cause of struggling to move tools inside the body: "Our hands can get in the way [...] but we cannot see the hands, we just see the tips of the hands [instruments], and so we say to ourselves, 'but why are her tweezers not grabbing there?' Because she simply cannot do the movement." (P8_{mentor-S5}).

Performing Gestures on the Patient Body. We observed moments where mentors actively performed gestures to further gather information examining the material conditions—the body. Here, mentors take the role of the operator to understand different aspects of the surgery. They may need to palpate or touch structures to feel their stiffness. This is because in some situations, mentors cannot fully understand the quality of gestures that the mentee performs exclusively through observation, as performing surgery heavily involves the sense of touch—e.g., changing how a gesture is performed depending on the stiffness of tissue. We observe in particular two different goals of performing action. One goal is to understand whether an instruction is not well understood or if the current situation makes it difficult to perform a gesture. When mentees struggle to execute an instructed gesture, mentors may try to perform their own instructions to determine if the unsuccessful gesture is caused by the mentee's technique or by the unfitness of the instruction given the current situation. A second goal is to verify the body regarding safety of action. For example, finishing dissection to verify that the instructed gesture can be safely performed, moving around organs to identify and locate the important structures not to be wounded, or looking for the source of bleeding making sure there are no important vessels nearby. This verification is a way to have more control over the situation, when visual information is not enough, as control is a prerequisite for many mentors before focusing on providing tailored support: "I cannot let him operate if I am not in total control" (P6_{mentor-S5}).

We have so far detailed the different cues that let mentors identify mentees' fear, mentees' fatigue, mentees' expertise as well as surgical risks. This information in turn lets mentors diagnose mentees' needs. Beyond these intraoperative needs, mentees eventually need to develop autonomy in the long term. In the next section, we detail how mentees develop autonomy and the role of physical distance.

6.3 Mentors Take Physical Distance to Develop Mentee's Autonomy

As the goal of mentoring is training the next generation of surgical workforce, learners need to eventually become independent. We find in our study that for surgeons to transfer responsibility and create space for autonomy to develop, they take physical distance, something that first requires trust.

6.3.1 Mentees Need First to Gain Trust From Mentors. The first step toward autonomy is for mentors to trust mentees, to progressively delegate parts of surgery involving more and more risks. This was both mentioned by a mentor and a mentee. This way, mentees have more opportunities to confront difficulty and acquire expertise. Nonetheless, this requires several instances of collaboration, as P5 points out:

“Concerning the teacher–student relationship, I think that the time when you let your student face the difficulty, it comes later. I think it comes after 5, 6, 7 procedures” (P5_{mentee-S10})

We observe that mentors build trust through discerning characteristics in the mentee, which include humility, capacity to listen, appropriation of the mentor's technique, acceptance of the mentor taking over, competence, and adequate management of safety. Nonetheless, mentees cannot practice autonomously as long as the mentor is present.

6.3.2 Mentor's Presence Hinders Autonomy. The presence of mentors in the operating room can prevent mentees from confronting technical difficulty, but more importantly, it limits the number of opportunities mentees face to develop their skills in making decisions, managing fear and developing their own surgical style. These aspects were developed both by mentors and mentees. We identify two reasons for presence hindering autonomy. First, mentors reassure on safety in the form of implicit validation as soon as they are present, while, to learn surgery, it is important *“to be confronted with stress”* (P4_{mentee-S1}). Second, mentors have a strong desire to control the surgery, sometimes aiming at controlling mentees' gesture in detail. One mentor mentioned that they expected to see in the mentee's gesture *“almost exactly what [they] would have done”* (P6_{mentor-S6}), and that *“the idea is that even if it is not me operating, it is as if it were me operating”* (P6_{mentor-S6}). In another similar case, we observed a surgeon repeatedly pointing toward a target while their colleague was operating. Aside from its communicative function, the surgeon explained that they gestured because they were *“in the movement”* (P8_{mentor-S11}), they *“lived the thing”* (P8_{mentor-S11}), and to be *“on the alert”* (P8_{mentor-S11}). The other surgeon understood this pointing as a *“reflex”* (P7_{mentee-S11}). While in this case the colleague did not aim at taking control of the surgery, they wanted to influence the operating surgeon, to see the execution of the gestures they envisioned.

In addition to controlling gestures, mentors often also take the lead concerning the strategy, as their intuition can lead to a more optimal path toward a goal, even if the mentee could have managed on their own had they had more time. The motivation behind the desire to control is often providing the best quality treatment to the patient, but as P10_{mentor-S4} explains, it can also result from mentors being *“impatient”* (P10_{mentor-S4}) and frustrated to see very slow progress:

“We are not gonna lie to ourselves, in general, surgeons are a bit impatient by nature, we need things to move forward, to go fast, we always have a lot of things to do and therefore it is a bit hard to watch things move slowly. And that is one of the things that is a bit difficult, to try to control yourself so that you do not constantly say ‘wait, I will show you’, ‘wait, look’ ” (P10_{mentor-S1})

Although the control mentors exert can provide opportunities for mentees to perfect their surgical skills by observing gestures in detail and an optimal strategy, it hinders autonomy. The fact that mentors take over can sometimes be *“frustrating”* (P3_{mentee-S4}, P4_{mentee-S1}), and, prevent

mentees from experiencing the difficulty necessary to develop skills and confidence around their own operating style, as P3 explains:

“It is very hard to help because even when I help mentees, we want them to do what we do, and what we would like to see. But [...] [with] two different surgeons, there are no two exact same gestures, the exact same steps, and so on. So it is very difficult to help while letting the other surgeon develop and refine their own technique, which will not necessarily be the same as ours” (P3_{mentee-S4})

The strong desire of control changes depending on mentoring style, in particular, according to the mentors’ experience and personality. We heard opposite opinions in this sense, for example P6_{mentor} expressed that novice mentors, that are starting in their career, dare *less* to impose themselves and take over the operator role as opposed to experienced mentors. In contrast, P3_{mentee-S4} believes that novice mentors take over *more* often as they have less experience to make up for potential complications that mentees could create and are less flexible in terms of the various techniques to perform surgery.

6.3.3 The Need for Presence Varies Depending on Mentees’ Expertise. We heard from participants that the need for presence decreases as mentees accrue experience, and thus the feeling of confidence in addressing unexpected complications increases. In the first stages of learning, mentees are dependent on mentors to finish the surgery: *“I was really struggling and I was really happy that he was there” (P3_{mentee-S4})*. However, when mentees gain in seniority, they *“no longer need the comfort of someone near” (P7_{mentee-S5})* because they feel confident recovering from potential errors. Nonetheless, even if mentees do not need mentors’ presence for reassurance, they can need mentors to be present for instructions. For instance, during S4, the mentor had to manipulate tissues to model a specific exposition technique requiring subtle ways to position tools to hold organs in mid-air equilibrium.

Expertise nonetheless can be bound to particular procedures, therefore independence is not achieved in absolute terms: senior surgeons can consider themselves as non-experts, like residents in some aspects, when they train on a new surgery. For example, when we observed an experienced surgeon learning to perform a radically new surgery (S11), which involved a different approach and technique, the need for the mentor’s presence was particularly important for reassurance, even if they felt comfortable being alone for other procedures. Even if they are experts, they also need fundamental advice on the steps of the new surgery, how to use the new material properly, what posture to adopt as the technique was new to them. Once they acquire this knowledge, their seniority enables them to face the diversity of cases independently. Conversely, we observed junior surgeons learning surgeries where they mastered the fundamental knowledge of surgery and were seeking to gain experience on the diversity of cases they could encounter. Thereby, the type of expertise mentees seek from mentors depends not only on their seniority, but also from their experience on a given surgery. When doing a new technique for the first time, the difference between residents and junior surgeons, or junior surgeons and senior surgeons, is that the gesture of the latter in both cases is safer even when they do not master the surgery, because they are *“more likely to be self-inhibited than to go off and do anything” (P10_{mentor-S4})*. Thereby, P10_{mentor} found it difficult to mentor residents in robotic surgery when they do not master dissection, and prefers that they acquire dissection skills in open surgery before operating with the robot. This shows how the distance created by the robot requires mentees to be autonomous in the safety of their gesture.

6.3.4 Mentors Take Distance. In this section, we share the different strategies mentors made explicit to create distance and create room for independence to develop. Figure 3 summarizes the different intermediate steps presented in this section that let mentees progressively gain autonomy as mentors take distance.

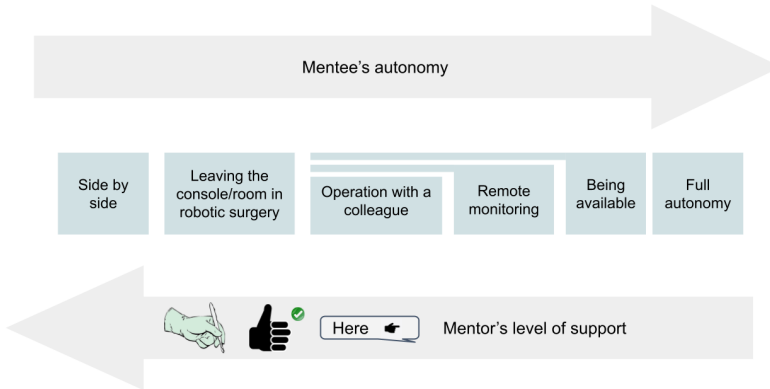


Fig. 3. Intermediate steps between full mentoring and autonomy

In robotic surgery, the form factor of the technology enables a progressive process of taking distance. As mentors can take their heads out of the robotic console, this can create distance with the mentee for a few moments without stepping away from the room. Here, the mentor does not guide or take over, therefore, the mentee is confronted with the difficulties of the surgery. This strategy lets mentors give space and impose a constraint (lack of vision) that removes the temptation to control. Still, mentors remain close to take over if needed. To further increase distance, mentors can leave the operating room while remaining available, as the robot does not require an assistant to hold the camera and auxiliary tools. In open and laparoscopic surgery, mentors can stay in the room and not assist. However, $P6_{mentor}$ found that this strategy did not work well as, when mentors are in the room, they have leadership and want to advice on the course of action. Conversely to robotic surgery, this distant position does not enable mentors to switch between distant and close mentoring, as they would need to interrupt the surgery to replace the assistant.

Colleagues Can Be Intermediate Support. To nuance their absence, we observed instances where a mentor left a surgeon of roughly the same level as the mentee in their place. The difference between operating with a colleague of similar experience compared to a more experienced mentor, lies in the fact that the colleague does not take control in the same way as the mentor does. Colleagues take the role of mentors and provide advice, validate, help to eliminate doubt, and reassure through being there “just in case”, without taking over as often, as $P2_{mentee-S6}$ explains:

“The difference would be that we would basically help each other, give each other advice, but let the other work. And if ever the other is a bit in a difficult position, [we would say] ‘well maybe try this’, but without having the conviction that we know better than the other” ($P2_{mentee-S6}$)

In the same way mentors need to trust mentees to delegate their gesture, mentees need to trust their colleague when mentees learn a new technique with a colleague of similar expertise. However, unlike trust on experts based on their reputation, colleagues of similar levels of experience need to know each other personally before developing trust and thereby, letting their colleague perform

actions on one's patient. The sense of responsibility toward the patient and toward providing quality care can be felt in the possessive language surgeons use when referring to patients.

"When you do not know someone from A to Z, you do not know how they work. In fact, you are not going to entrust your life or the life of your patient to the person you do not actually know" (P7 *colleague-S7*)

7 DISCUSSION

Our study contributes to the understanding of mentoring practices in surgery. We provide a thick description [12] of how mentors first examine mentees to then diagnose their needs, and finally provide treatment by determining an appropriate mentoring strategy. Mentors *understand the mentee* through noticing cues on the surgical site view, such as hesitation or struggles when performing surgical gestures, and then actively gathering further information through inspecting the mentee's posture including how they handle tools, and through manipulating tissues. Our study shows that *mentees' needs* in surgical mentoring go beyond acquiring technical skills, as they require *creating circumstances* that contribute to effectively acquiring such technical skills. These additional needs include being spared from parts of the workload, to be able to focus on specific tasks, and being reassured regarding the safety of the surgery. They are a consequence of surgery being a long activity that requires a large number of skills, involving high risks. The mentoring strategies we observed are in line with the theory of apprenticeship [13], and complement the literature on surgical mentoring [8, 15].

With these results, we discuss the disconnect between telementoring systems and onsite mentoring practices, and show that the design of current systems limits the knowledge and skills mentors can transmit: (1) the mentors' inability to gather certain types of information prevents them from building the intuition needed when providing expertise; (2) as mentors cannot spare mentees through taking over or guiding action, mentees need to already have significant surgical proficiency; and, (3) complex gestures, usually explained through modeling, may simply not be transmittable with existing tools. Simply put, some skills are not *telementorable*. Finally, we reflect on implications for system design, and question the practice of telementoring as a replacement of onsite mentoring. We posit that telementoring can be used as a complement to side-by-side mentoring to obtain a higher pedagogical value.

7.1 Limits of Current Surgical Telementoring Systems

Current telementoring systems are predominantly designed under a videoconferencing paradigm, the real-time transmission of audio and video, with sometimes the added possibility for telestration [2]. Our results point toward a disconnect between these functions and the actual practices of mentoring. Existing functions simply cannot support mentors in performing certain practices remotely. We discuss in this section mentoring practices that are still not fully supported under current system design, also discussing how systems could improve support through new functions.

7.1.1 Understanding the Surgical Site. Capturing and transmitting video as done by current systems is not sufficient for the mentor to understand the surgical site, and therefore to diagnose mentees' needs. We identify three main limitations: visual access of the surgical site and mentees' posture in open surgery, visual access of tool constraints in minimally-invasive surgery and, access to haptic feedback.

First, it is key for the mentor to have a comprehensive view of the surgical site in open surgery. Although previous works on telementoring have explored head-mounted cameras through the Microsoft HoloLens [33] or Google Glass [32] to stream first-person video, the narrow incision size makes it challenging to capture a comprehensive view, especially when operating deep in the

patient. In addition, head movement can cause dizziness and require additional effort for mentors to realign the view with their understanding of the tasks [23, 52]. In minimally-invasive surgery however, classic or robotic, capturing the surgical site is trivial as the endoscope video feed can be easily streamed.

Second, mentors also need to look outside the surgical site to understand mentees' struggles, and give meaning to the gestures they observe in the surgical site. Thus, the second limitation we identify is failing to convey the mentee's posture and its relation to their hands in open surgery, and to their instruments outside the body in classic minimally-invasive surgery. Although some systems provide an external view in addition to the surgical site, such as the VisitOR1®, the camera is afar and thus the image may not be sufficient to provide intelligible information. It is necessary to capture a closer view of the mentees' posture, which is challenging as the operating room is dynamic, where various actors move and occlude external cameras. Previous work proposed fixing a GoPro camera to the endoscope, showing the expert's hand movement to create video learning material [29]. However, for telementoring this is probably inadequate, as this point of view does not record tool management between dominant and non-dominant hands, and, instrument range of motion with respect to the trocar, which sometimes can explain sources of struggles. Although adding more and more cameras might seem adequate to better understand mentees, this should be done carefully, as multiplying video sources may diminish their intelligibility [23, 29].

Beyond using vision, mentors also rely on touch to understand mentees. As mentors are unable to perform physical gestures remotely given current systems, it is thus not possible for them to feel the body through palpation, and thus nuances their up-to-the-moment diagnose of mentee's gesture and the surgical difficulty. This hinders their ability to understand if the reason behind a mentee not following instruction lies in incorrect comprehension or the patient anatomy. Integrating force sensors in the instruments could convey this information. Still, although studies have measured force applied to tissues to compensate for the lack of haptic feedback in robotic surgery [53] and to compensate distortion [44], the large size of current sensors is not yet suitable for real surgical settings. A more realistic approach could involve measuring the force applied to the instrument at the distal end, where the hand holds the instrument [41], as this does not involve inserting sensors into the patient. Besides the issues at the sensing end, there is also research to be done regarding the presentation of the sensed information. Providing a tactile or a visual representation of force have been explored in surgery [22, 42], although not for mentoring contexts. The question remains on whether these methods represent information such that mentors are able to understand the mentee.

7.1.2 Instructing. The telestration function that current systems provide, on their own, do not support mentors in conveying the same information as when they physically take over. This becomes clear in the robotic surgery observations where mentors had access to a pointer, but still took over during instruction (Section 6.1.1). This show there is a need to further investigate what are acceptable time thresholds when conveying instruction, as well as the information complexity and diversity that mentors can convey with telestration. Promising avenues beyond telestration could be virtual instruments overlays [28], hand overlays [38], or hand avatars for open surgery [58]. However, research has not yet shown which instructional needs these avenues can fulfill and which ones they cannot. Moreover, new instructional needs may appear in telementoring to compensate for the fact that mentors cannot perform actions when remote. This is the case of exposition, where remote mentors make do with the view, and interrupt mentees only in rare instances [31]. This suggests that telestration is not sufficient to seamlessly guide exposition without interrupting surgery. Capturing a contextual view around the surgical site may help the mentor indicate where to focus the camera. This capture is possible with the Enhanced Laparoscopic Vision System (ELViS),

which consists of two additional cameras on the trocar, at the back of the endoscope [55]. However, this system was studied in the context of safety, but its contribution to instruction still needs to be demonstrated. Eventually, increasing the ability for mentors to adjust exposition will also increase their ability to understand the situation, and to spare mentees from unnecessary struggles.

7.1.3 Reassuring on Safety. As our study shows, the mentor's presence provides reassurance in three ways: being there "just in case", explicit validation, and implicit validation. In situations where mentors cannot make themselves available quickly, as they are located far away, mentees do not have the reassurance that the mentor is available just in case. Still, current systems provide tools that mentors could use for explicit validation, for example, voice and gesturing tools, to alleviate mentees' doubts about safety, and to confirm and guide the mentees' actions. Still, systems lack tools to convey continuous *implicit* validation, as the remote mentor cannot perform secondary tasks that signify presence such as centering the camera. One could imagine that a physical embodiment such as a robot may be able to recreate presence, which has been shown to make students forget that the mentor is not physically present during cadaveric dissection [50]. Although systems have put forward the notion of remote presence, using terms such as Virtual Interactive Presence [49], MedPresence© or remote presence [50], it is unclear if they provide the outcomes of presence, in particular implicit validation. For example, systems may need to provide mentors with ways to continually show they are focused on the task, rather than embodying their physical presence.

While the avenues discussed above are promising, they cannot replace direct physical contact, and thus mentors cannot provide support remotely in the same way as they do when collocated. We acknowledge that telemanipulation could improve mentoring support, such as operating a surgical robot remotely, by giving the remote mentor mechanisms to act on the body. Nonetheless, there are a number of barriers that make this approach unfeasible, mainly legal responsibility across borders (of an institution or country), the high cost, and the technical complexity.

To summarize, under their current design, telementoring systems provide partial support for mentoring. They provide tools that mentors can use to help mentees when identifying gaps in their expertise, to share the load concerning the choice of actions, and to alleviate mentee's doubts explicitly. However, our results points toward telementoring systems lacking tools for mentors to convey complex instructions when filling the mentee's gap in expertise, to spare them from performing parts of the surgery, to provide continuous implicit validation, and to reassure mentees that they can take over if potential risks turn into concrete complications. By design, telementoring systems are limited when it comes to enabling mentors to create the necessary conditions for efficient learning, limiting therefore their pedagogical value. However, we argue that telementoring systems can have pedagogical value when they are used alongside onsite mentoring. The dual-purpose of surgery, providing safe care and training, makes the ambitious goal of achieving surgical mentoring entirely remotely paradoxical: it implies the physical absence of an expert and therefore requires a certain level of proficiency to manage complications independently, overcome blocking, and face the workload of long surgery, all skills that are learned given the mentor's ability to take over. This leads us to rethink telementoring not as a way to achieve mentoring entirely remotely, but as an integral part of onsite mentoring.

7.2 Remote Mentoring as Onsite Mentoring Companion

Our study shows that remote and onsite settings have different limitations and opportunities for mentoring practices. Certain needs of mentees intrinsically require mentors to take over. This is the case when mentees need to be spared from workload, and be reassured just by knowing that the mentor can takeover in case of emergency. Other needs may be fulfilled without requiring

the mentor to be present. Novel technologies could address for example the need for implicit validation (achieved through mentees feeling mentors' presence), or for complex explanation (achieved through mentors manipulating the body). We thus argue that telementoring systems should not aim at reproducing and replacing onsite mentoring, the current dominant view, but rather aim at being part of a larger training process.

7.2.1 Preparing Telementoring Through Onsite Mentoring. Onsite mentoring can be a place where two surgeons build rapport, trust, and develop a base set of skills in preparation for later remote interaction. In our study we observed that, while mentees can trust mentors more easily when they have a reputation as experts, mentors need to work together with mentees to trust their gestures, and feel confident delegating surgery. Even though the remote mentor does not share the same responsibility as onsite mentors concerning the success of the surgery, building a relationship before telementoring could strengthen, on the one hand, the trust mentees have in mentors and therefore their willingness to listen and incorporate advice, and, on the other hand, the trust mentors have in mentees and therefore their willingness to repeat the mentoring experience. For example, in cases when mentors become more comfortable delegating gestures as a consequence of mentees following a technique in the same way as the mentor, building this understanding previous to telementoring sessions can increase the trust between both surgeons.

7.2.2 Alternating Between Onsite and Remote Mentoring. With an established relationship, telementoring can be a way to gain experience, follow-up more frequently, and show how to adapt previously learned techniques to a diversity of situations. Telementoring can play a role in *perfecting skills* already acquired under collocated supervision. At a stage where mentees have the necessary knowledge and skills to perform certain operations autonomously, a remote mentor can provide timely feedback to incorporate new knowledge. To actually learn the new skill, mentees need nonetheless to feel confident following new directions without a mentor being able to take over. The positive impacts can potentially permeate to clinical benefits, as a mentor guiding toward an optimal gesture can translate into a reduction in operative time. This model of alternation has been explored in one specific case of clinical mentorship, where mentors stayed in touch remotely while performing quarterly onsite visits [10]. Still, this experience was asynchronous (e.g., email) rather than communicating during live surgery.

Even if telementoring is traditionally seen as a bridge to reduce distance between institutions, we propose to explore the value of intra-institution telementoring. First, this setup can create distance within an institution, which can be used to **support autonomy development** through creating an intermediary step between the mentor being inside or outside the OR. Indeed, our results show that when in the operating room, mentors can have a strong leadership and desire to control, which can prevent mentees from experiencing learning opportunities. As experienced surgeons can usually perform safe gestures, they do not need constant surveillance. By staying in their office, mentors could monitor progress, give validation feedback, or provide instructions in a way that is regular but not necessarily continuous. The cost of taking over is higher in this setup as it requires walking to the OR. Mentors would therefore have an incentive to instruct first, and let mentee try for longer, although given they are present in the hospital, they could still come if they judge necessary, thereby guaranteeing safety. In a study of intra-institution telementoring [38], mentors saw the benefit of having mentees carry out more work during the surgery while still under supervision. Moreover, one mentor reported an increased in their ability to guide mentees, and one mentee reported better understanding of technical expectations. Indeed, previous work has demonstrated that telementoring can improve the quality and attention to instructions [46]. Another study explored telementoring while operating in an adjoining room [9]. This setup led to an efficient use of the mentor's time, but more importantly, mentees appreciated being able to

develop confidence and skills in a protected environment, as the mentor can be physically present quickly. As mentees developed confidence, they reduced their need for reassurance therefore developing autonomy. These insights confirm that telementoring systems can, not only spread knowledge outside of an institution, but they may also improve learning within an institution.

7.2.3 Vicarious Mentoring: Simultaneous Onsite and Remote Mentoring. The traditional telementoring approach of having one remote mentor and one local mentee that operates, meets its limits when addressing mentees' needs to be spared from performing parts of the surgery. We envision the use of telementoring systems for *vicarious* mentoring, using the telementoring system to employ one surgeon as mentor by proxy, reifying the remote instruction to assist the main surgeon. This is inspired by the accounts of P7 and P8 who, after traveling to observe an expert model a specific procedure, provided mutual support through reassurance and collective memory when performing the initial operations at their home institution. In these case, a remote mentor could have guided one of the two surgeons in assisting the other. As our study shows that sparing and sharing the workload is one way to support learning, we could imagine a situation where responsibilities are split between the two colleagues. For instance, one could be in charge of exposition through expert advice while the other could be in charge of dissection. In this case, we can envision that the two surgeons alternate the role of mentor-by-proxy and mentee. We note that assuming colleagues' roles during surgery for learning is a phenomenon already observed in the literature. Mondada [35] reports on the observation of cases where one surgeon operates and another presents the live-streamed case to a remote and international audience (teleeducation), where surgeons switch between the roles of expert, colleague, co-teacher, or mediator between the operating surgeon and the audience.

7.3 Conclusion

We present an empirical study of onsite surgical mentoring, where experienced surgeons guided learners to expand their already-acquired base surgical skills. We observe ten surgeons throughout 11 surgeries and conduct semi-structured interviews with self-confrontation. We find that mentors understand the situation through observing the surgical site, observing the mentee's posture and through performing actions on the patient body. Mentors not only satisfy mentees' needs for acquiring expertise, but also their need to be spared from parts of the surgery and to be reassured on safety. They eventually take physical distance to let mentee develop autonomy. With these findings, we discuss the limits of current telementoring systems and how those needs could be better answered remotely through the use of technology as well as through new organizations. We reflect on how telementoring can complement onsite mentoring both between and within institutions, in particular for autonomy development.

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A SEMI-STRUCTURED INTERVIEW QUESTIONS

A.1 Part 1: Introduction (7min)

- Can you recall in a few words what the surgery consisted of? What made this surgery particular?
- Before starting the surgery:
 - Was there a particular aspect that you were thinking about?
 - Besides doing surgical gestures, were there other things that preoccupied you? (Ex: Time? Risk?)

A.2 Part 2: Auto-confrontation (30 min)

After showing the 30s preceding an event

- What were you doing / were they doing? What happened before? What role did you have? What was happening at this moment which is not captured in the recorded video? What is going to happen afterwards?

After showing the 30s after the event

- What were you thinking about? What were you feeling? What brought you to do that/those action(s) (gesture, look, speech...)?
- *Only for mentor* - How did you know that about the mentee? (following up on the assumption they express about the mentee)
- *Only for mentee* - How did the mentor's presence add to this particular moment?

A.3 Part 3 [Mentor]: Further questions (not related to specific moments) (15 min)

- Could you tell me about a moment where you had difficulty understanding what the mentee was doing?
- Could you tell me about a moment where you felt the mentee needed you particularly. It could be at the beginning, in the middle or at the end of the surgery. How did you know they needed you?
- If you could only choose one thing that the mentee learned or improved during this surgery, what would it be?
- Conversely, could you tell me about one thing that the mentee could have learned or improved but you believe they did not learn?
- Finally, if the mentee was wearing an invisibility cloak that prevented you from seeing them outside the surgical site view, would it impact learning and collaboration? How?

A.4 Part 3 [Mentee]: Further questions (not related to specific moments) (15 min)

- Could you tell me about a moment where you felt that the mentor did not understand you correctly?
- Could you tell me about a moment where you felt you particularly needed the mentor? It could be at the beginning, in the middle or at the end of the surgery. Why did you need the mentor?
- What is one remarkable thing you learned or improved during this surgery? Why is it remarkable?
- Conversely, what is one thing you could have learned or improved during this surgery, but did not?
- Finally, if you were wearing an invisibility cloak that prevented you from being seen outside the surgical site view, would it impact learning and collaboration? How?

A.5 Throughout the interview, remember to ask

- *When a specific moment is identified* - What would it change if this (expertise, setting, time, information availability...) was different?
- *When an exceptional event is identified* - How does this event unfold usually?
- *When a usual event is identified* - Do you recall one time things did not go the usual way?
- *When a problem is identified* - In an ideal world, what would the situation look like? If you could change one thing, what would it be?

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