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Videos are a powerful media to learn activities through guided physical training such as surgery, especially when they are produced following human learning models and not as "how-to" videos. However, their success greatly depends on how they are integrated into the extensive curricula of domains where learning occurs through guided practice. In this work, we investigate the impact of integrating video as a learning tool into the learning curricula of surgery. We created a pedagogical video on surgical hysterectomy through a model based on the Conceptual Fields theory (Vergnaud) and performed two rounds of interviews with seven medical residents, who watched the video freely during their residency in gynecology-obstetrics as they trained with experts. We find that videos can complement guided physical training, as they can provide the rationale behind expert action, something that is difficult to explicit during guided training. Still, their linear and static nature limits their integration as true adjuncts. We discuss our vision of moving towards interactive videos created with an *ontological* approach, developed in a workshop with four expert surgeons, which involves the ability to navigate through levels of information and layers of representations, so that experts can represent information to learners according to pedagogical models that complement their complex and extensive learning curricula.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: video-based learning, Conceptual Fields theory, surgery, guided practice

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1 INTRODUCTION

Recorded videos are a widely-used media for learning physical activities, as they constitute learning opportunities that are accessible on-demand without requiring an expert to be available. Much of the videos for learning take the form of *instructional*—or *"how-to"*—videos [6], as their production is traditionally approached as a matter of putting together sequential steps that describe an activity. Previous work has identified this is a consequence of commercially-available video editing tools, which offer functions to cut and assemble video segments that can be exported as flat files, resulting

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in a chain of instructions demonstrated visually [4]. The content is thus demonstrational rather than pedagogical, mainly focusing on non-technical skills, lacking both multimedia design principles (e.g., content visualization to improve attention) [72] and consideration for learning theories [68].

Formalizing the *content structure* of video can improve learning, facilitating the search for relevant information, and enhancing viewers' experience (e.g., their engagement in learning) [70, 74, 91]. Indeed, when learners are confronted with learning videos where content is not explicit, they use the pause function to identify by themselves structural elements such as actions and objects within a task [79]. Previous HCI and CSCW research have thus explored methods to identify structure elements, for example through outsourcing the identification and labeling of learning subgoals to learners (*learnersourcing*) [87]—as presenting subgoals reduces cognitive load therefore improving learning [13]—or through automatically generating a multi-level hierarchical event structure [78]—which facilitates understanding instructions [90]. These methods are *ex post*, extracting structure of already-available videos. One way to create learning videos *ex ante*, modeling content structure before creating the video, is to use human learning models.

Using *human learning models* to organize the underlying structure of videos before production can bring further benefits, particularly in surgery. Indeed, integrating research-based theories of human learning and evidence-based principles for the design of effective instructional videos has been shown to improve understanding of the principles taught in surgical education [18] by reducing extraneous cognitive processing during learning, and fostering generative processing [52]. Still, learning surgery involves various activities, including assisting lectures, reading textbooks, watching videos, and participating in *guided physical training*, learning side by side with experts while they work [66]. The challenge is to effectively integrate these learning opportunities, as Peahl et al. [63] point out: *"standalone video interventions are likely insufficient to create meaningful change and should be explored as adjuncts, rather than replacements to usual clinical teaching"*.

We set out to explore the interplay between pedagogical videos and expert guided training. We focus on the domain of surgery as videos have become a frequent medium to teach [4]. They contribute to the acquisition of many of the skills required to master the activity, such as performing surgical gestures, acquiring knowledge on the surgical intervention or making medical decisions [12, 19, 29, 36]. To create the pedagogical video, we first created a pedagogical model of a surgical procedure with an expert surgeon in Gynecology (co-author) using the Conceptual Fields learning theory [83]. The procedure is a hysterectomy by laparotomy, the removal of the uterus through an open technique, where the surgeon makes a large incision through the skin and muscle of the abdomen to see and operate on the various organs, tissues, and blood vessels. We focused on this procedure because it is very common but still challenging to learn for medical residents. Then, we video-recorded the procedure and edited the footage.

We conduct a study with seven residents where we integrate the pedagogical video to the residency of first-year medical students, with little hands-on experience—less than 5 encounters. We interviewed participants once, instructed them to watch the video as many times as they wanted while they learned in the Operating Room (OR) during their residency, and conducted a second round of interviews two weeks later. Our first finding is that guided training is a challenging environment for learning the *rationale* behind experts' actions, as the stress and time constraints take priority. Second, we find that pedagogical videos are a powerful complement to guided practice, as they can give meaning to and prepare for future practice, and as practice can modify and provide reflection about previously acquired knowledge through video. Lastly, we see that participants identify relations between the recorded procedure and other procedures they encountered during their residency, relations that had not been anticipated by the creators of the video, thus appropriating the video to their advantage. We conclude by presenting our vision for the future of learning videos, developed in a workshop with four surgeons, to enable an *ontological* approach for content creation, and discussing the interactive needs for navigating different layers of information.

2 BACKGROUND: SURGICAL PROFICIENCY

Surgery is a complex activity that involves extensive and diverse expertise [37] to correctly perform surgical gestures — actions performed on the patient's body, with or without instruments, such as making an incision, dissecting, suturing, and coagulating. This means surgeons acquire a large number of diverse skills, both surgical and technological (e.g., interacting with surgical robots), which sometimes come into conflict [3]. Surgical skills are both technical, for example dexterity and knowledge of instruments, risks, procedures and anatomy; and non-technical, as the intervention plan, decision-making, leadership, teamwork, situational awareness, and anticipation. One key skill is exposition of the surgical scene i.e., to *"present the organs in the isolating style of an anatomic atlas [to] show neatly separated organs"* [35].

2.1 Learning From Experts Through Guided Physical Training

The introduction of apprenticeship in surgery at the beginning of the XIXth century, the well-known Halstedian model *"See one, Do one, Teach one"* [34], greatly improved surgical education. Here, an experienced mentor instructs a trainee, shares collective knowledge, and teaches surgical techniques by demonstration and repetition. This change meant that surgical knowledge and techniques are now learned by instruction and example rather than trial and error [27]. Prentice [66] defines this as a *guided physical training*, or *guided practice*, where the trainee directly observes and then imitates the actions of a skilled mentor, both in the OR and during clinical examination [23]. Because apprenticeship takes place in *real conditions*, it is an effective learning technique, but can have direct consequences on the course of the surgical intervention, for example by making it last longer [89] and therefore riskier, from lengthening the anaesthesia time. Surgery, therefore, is a dual-purpose activity: providing patient care and at the same time teaching medical students. This introduces a new challenge: one activity may come in conflict with the other. For the student, *guided physical training* translates into years of observing surgical interventions or participating very little as a second assistant, then, slowly moving to first assistant under strict control of the senior surgeon during the six to seven years of residency. It is during this residency that medical residents undergo clerkship, or rotations, where they spend time in patient care environment with limited workload.

2.2 Developing Clinical Skills Through Video

While *Halstedian* apprenticeship [34] still remains the golden standard in surgical training, the learner is only allowed to perform actions on the patient once they have achieved a certain level of proficiency. More and more, learning tools outside of the OR have come into the spotlight, in particular for two reasons: first, the constantly increasing number of residents [20] challenged traditional approaches of learning through direct observation in the OR [64], which limits the number of opportunities to learn [61]. Second, even when access is possible, early-career residents do not feel safe learning through guided practice because it can involve practicing on patients with little prior experience [69]. Video in particular has been shown effective as an instructional method for learning clinical skills such as oral medication administration [36], learning the Handling Totally Implantable Access Ports (TIAP), a nursing procedure [12], or improving the residents' ability to perform laparoscopic right colectomy, a digestive surgery procedure [19]. Although these works demonstrate how videos contribute to the acquisition of competencies for clinical performance, the authors do not describe the creation process, neither do they use models to structure the content.

3 RELATED WORK

3.1 Using Videos for Education

Videos are a common media for education, both in formal (e.g., MOOCS) and informal platforms (e.g., YouTube). As suggested by Bétrancourt et al. [11], the creation of the videos and the decisions taken during this process—in other words, what is to be learned from the video—will impact learning outcomes, with different approaches to educational videos that can be divided into three categories. First, the *representational approach*, or selecting the type of media to include in the video: static (images) vs. dynamic formats, where the latter can include pure video, screen capture or computer-generated graphics. Second, the *cognitive and perceptual approach*, or applying cognitive theories to content production and edition. Third, the *instructional approach*, or the way of instruction, including using video as complement to face-to-face learning, as tutorials, showing an expert do a task in real situations to engage in reflection, or having students design videos as a learning process. Instructional videos are for executing tasks (e.g., repairing a bike), however, for learning purposes, these videos are limited as they do not necessarily explain the *principles* of the task, which, according to Eiriksdottir et al., *"provide information about rules and regularities governing the task and task domain"* [24]. Instructions alone do not inform on how a system works, on its different elements and how they relate, information which is essential for learning to occur. A video for learning can be positioned within these approaches, depending on the targeted activity, the teaching style and the audience, among other factors. Because of the limitations of instructional videos, our approach is distinct from the three categories presented above, as it includes the principles of the task taught as a result of using a model of human learning.

3.2 Structuring Content for Educational Videos

There are two main approaches to structure the content of a video. First, *ex post*, identifying such elements on already-available videos. For example, using audio transcription and semantic annotations to perform automatic segmentation of video lessons into scenes [74], or text and acoustic properties of the videos to form a hierarchical content table (similar to a table of contents available in a textbook) [56]. Other research articles specifically on MOOCs have proposed ways of representing information (on video or other media) in a structured way, such as a system that recommends lecture videos across different courses by considering both video contents and sequential inter-topic relationships [91] or an interactive framework in which groups of learners are formed on demand and then proceed through a sequence of activities that include synchronous group discussion about learner-generated responses [17].

The other approach is *ex ante*, relying on rules and guidelines to produce the structure at creation time, which is especially relevant when the video creator has a specific goal in mind. For example the fact that length impacts engagement, with shorter videos being more engaging [33] or tips for reducing production time and increasing long-term usability [59]. Guidelines include how to reduce cognitive load, increase engagement and promote active learning [9], how to increase engagement through dynamic drawing on a board rather than using already-produced text [53] or on how to present the speaker, as a monologue-based video or dialogue-based video [60]. A more promising way to shape content during the creation of video, is to use cognitive or pedagogical models. For example, enabling learners to elaborate a hierarchical structure of the content through its segmentation [7] or through the use of pauses [54], as this structure aids understanding. Multimedia design theories include the Cognitive Theory of Multimedia Learning (CTML) [51], and the Integrative Text and Picture Comprehension (ITPC) [70]), which posits that mixing images and real video brings the benefits of both, namely conceptual learning (images, diagrams) and observational learning (real video) which triggers mirror neurons and automatization.

The use of theories to produce videos for learning has shown how the success of this strategy greatly depends on the integration of the video into the learner's path. One work evaluated videos produced using The Four Components of Instructional Design theory [81] with the goal of improving learning outcomes [63], however the authors did not use a learning theory to guide the creation of the learning video, but a multimedia design theory.

3.3 Integrating Videos Into the Learning Curricula

Integrating videos into real learning curricula remains a challenge, already identified in two recent systematic analyses of video for learning. They highlight that video needs to be adjusted to align it to learners' prior knowledge [65], and that video should be incorporated into the learning flow that involves performing the task [29]. Furthermore, a recent study on video annotations vs. quizzes concludes that prior knowledge plays a critical role in selecting the appropriate learning strategy [55]. Very few studies have explored the benefits and challenges of integrating pedagogical videos, that structure content according to learning theories and models, to real learning curricula in all its complexity. To our knowledge, only one study used cognitive theories to create videos (Dual Code Theory and Cognitive Theory of Multimedia Learning) and explored them as adjuncts to the participant's learning careers [76]. Authors show pedagogical videos can improve attention and thus benefit learning, but they do not investigate the influence between video and practice.

The intricacies of pedagogical materials for learning with real guided practice learning remain unstudied. To our knowledge there is no previous work that has, first, using an *ex ante* approach, created a pedagogical video based on a human learning model for a fundamental definition of a task being taught: identifying and structuring its composing elements, whether physical (the actions), or mental (the knowledge and decisions based on this knowledge); and, second, used this video to study its influence on guided practice and vice and versa.

4 PEDAGOGICAL MODEL AND CREATION OF THE VIDEO

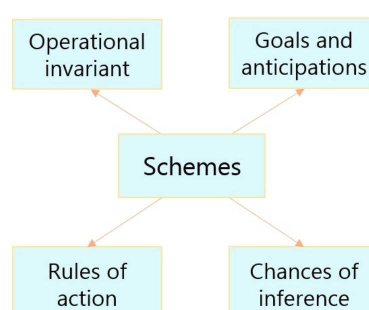


Fig. 1. Conceptual Fields theory Schemes

We approach the creation of a pedagogical video through the theoretical framework of constructivism, which is defined in opposition to behaviorism [28], considering cognitive development as a construction of active learner reorganizations and not as a linear process, being the result of maturation and stages [26]. Here, learning is an interpretive and recursive building process of constructing meaning, as active learners interact with their surroundings, the physical and social world. Having difficulties with meaning-making engenders progressive shifts in perspectives that can be generalized across experiences and that often require the undoing or re-organization of earlier conceptions [26], generalizations called OPERATIONAL INVARIANTS. Deriving from this theory in the field of psychology, Vergnaud proposes the Conceptual Fields theory [83] (Figures 1 & 2). According to Vergnaud, *"The theory of conceptual fields is a cognitivist theory which aims at providing a coherent framework and some basic principles for the study of the development and learning of complex skills, especially those related to science and techniques"* [82]. The Conceptual Fields theory presents the relations between explicit knowledge and implicit OPERATIONAL INVARIANTS that partially constitute schemes [83].

Schemes are cognitive activities, composed of up to four categories: GOALS AND ANTICIPATIONS, RULES OF ACTION, possibilities of INFERENCE IN A SITUATION, and OPERATIONAL INVARIANTS. Their function is *"to organize and generate the activity in situation"*, they are both *"producers and products"* [85]. The learner has to be able to represent given situations in a conceptual field, and either activate a relevant scheme to solve the problem the situation causes, or *"map this situation into a symbolic representation and then operate inside this representation until the solution is reached"* [83].

The OPERATIONAL INVARIANTS represent the key elements of the model as they are used to select and interpret the relevant information to solve the problems that individuals face in complex situations, such as surgery. They enable the learner to capture, select and integrate the information present in a situation, and to process it given the categories of thought that they have developed. The Conceptual Fields theory has been used before in the domain of surgical education to describe the reasoning behind the surgeon's actions [80], or as a basis for the creation of a simulation-based Intelligent Tutoring System (ITS) for learning percutaneous orthopedic surgery: TELEOS [48, 49].

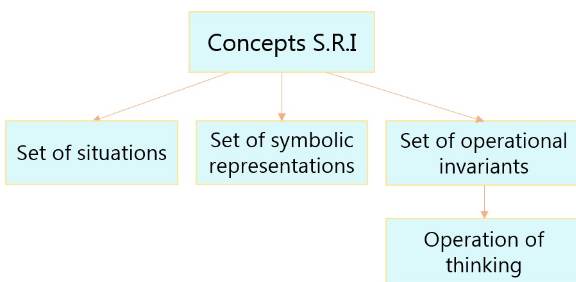


Fig. 2. Conceptual Fields theory Concepts

Through the use of Conceptual Fields theory in TELEOS, researchers were able to better understand and identify the structuring points of professional expertise in the surgical activity of sacroiliac screwing, an orthopedic surgical procedure. The model also enabled to better understand how certain sensory-motor patterns are acquired and to define and experiment later on some of their learning conditions. The conceptual fields theory has also been used to describe the learning of many other complex activities outside the field of medicine such as cow milking [77] or learning numbers in primary school [31]. Thus, we hypothesize that using this theory to create a pedagogical video for learning surgery learning, as it enables the identification and definition of the explicit and implicit knowledge necessary to attain proficiency. Moreover, it aids understanding how to expose this knowledge to attending surgeons, and how learning the surgical procedure occurs during guided practice.

4.1 Modelling the Hysterectomy by Laparotomy

We focus on hysterectomy as it is a common procedure, 80.000 cases each year in France[1]. Specifically, in open hysterectomy, where training still remains challenging for residents as very few images are accessible due to the complexity of recording—mostly setting up multiple points of view and sterility—as opposed to the laparoscopic technique (performed through small incisions) where images are easy to record by virtue of the used endoscope [2]. While open hysterectomy is less common than its laparoscopic counterpart (15.000 cases each year in France), it remains a key surgery to master, as in certain cases the laparoscopic option is not a viable alternative.

To build the model of hysterectomy by laparotomy, we analyzed six different videos of hysterectomies, we directly observed 15 hysterectomies, we drew from literature on hysterectomy [16, 44, 45, 75], and we interviewed two surgical experts on hysterectomy as well as one medical resident in gynecology obstetrics. We use five different classes, directly derived from Vergnaud's Conceptual Fields theory, making partial use of the model as we leave aside the *inferences* in situation which are the reasoning to compute the rules and expectations [84]. This is because inferences are created when learners are confronted with a target ACTIVITY as they perform it, and in video they only watch activities, they do not perform them.

[1] https://information.tv5monde.com/terriennes/hysterectomie-ou-ablation-de-l-uterus-une-operation-en-baisse-dans-le-monde-360678

The resulting classes in our model are the following.

(1) Activity: The surgical steps of hysterectomy by laparotomy, from which are derived the *actions, goals* and *anticipations*. Activities are organized in an identical way for a given class of situations by schemes.
(2) The intervention domain: the situation in which the categories of the scheme specifically apply, which can be as general as the intervention—total hysterectomy by laparotomy in our model—or specific to peculiarities of the patient—e.g., the extension of the endometriosis.

Schemes are composed by the following three categories of the model:

(3) Actions, goals and anticipations: the surgical gestures to perform to fulfill the activity objectives, from general to specific, including the expected results of these gestures.
(4) Rules of action, information gathering and controls: A *rule of action* is a rule (e.g., if this, then that) which conditions how the surgical actions are performed, depending on the resulting value of different variables evaluated as stated in the rule. *Information gathering* and *controls* are the actions of verifying the state of the world to identify the values of the different variables in the situation, at each step of the hysterectomy by laparotomy.
(5) Operational invariants: A concept that the learner identifies when they find common meaning in different types of situations. Each situation partially deconstructs the concept, as these are dependent on the unique situation. Learners thus integrate these concepts in a conceptual field. In the case of hysterectomy by laparotomy, the Halban fascia is white, soft and shiny; a concept that is considered true in certain situations, depending on the results of the rules of action and depending on the activity being performed.

Through our empirical work of observation, conversation and investigation, we settled on nine activities: (1) Positioning of the patient, (2) Incision and inspection, (3) Opening of the peritoneum and exposing of the round ligament, (4) Opening of the broad ligament, (5) Ureter identification and section of the lumbo-ovarian, (6) Bladder detachment, (7) Ligation and section of the uterine pedicles, (8) Vaginal opening, (9) Closure of the abdomen. The full model with all the activities can be found on Appendix A, we provide an excerpt detailing activity Number 6 in Table 1.

Activity	**Actions, goals and anticipations**	**Rules of action, information gathering and controls**	**Operational invariant**
6. Bladder detachment	1. Mobilize the bladder: begin mobilization at the midline of the cervix	Before mobilizing the bladder, palpate the cervix from the anterior and posterior sides. If you palpate the cervix, then this will allow you to check its position	The bladder frequently drifts laterally due to fibroids or adhesions. Palpation is also essential to estimate the cervical length. Second, mobilizing the bladder prevents bleeding from the lateral vesico-uterine ligaments.
	2. Lift the anterior leaflet of the severed broad ligament		When the surgeon lifts the anterior layer of the broad ligament, the vesico-uterine space opens spontaneously where the first incision should be made, in the center of the cervix.
	3. Push the scissors vertically to the cervix and cut the connective tissue	Identify Halban's fascia. If you push the scissors vertically at the cervix and cut the connective tissue, then this will reveal Halban's fascia. Check for fat. If you encounter fat, then change the route. Encountering fat means the dissection coming too close to the bladder.	Halban fascia is white, soft and shiny. The fat belongs to the bladder. Its presence indicates that you are not in the right plan.

Table 1. Activity 6: Actions, goals and anticipations, rules of action and operational invariant

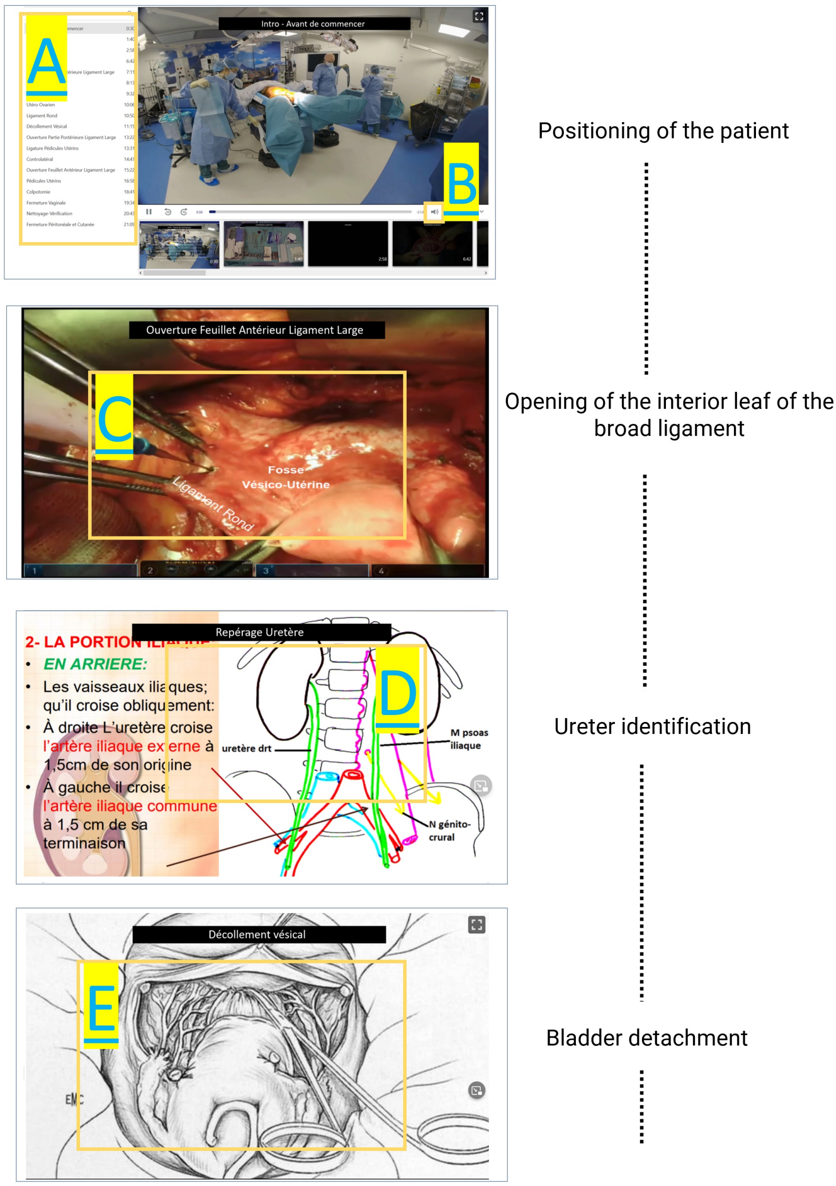


Fig. 3. Four activities of the open hysterectomy video: 1. Positioning of the patient, 2. Opening of the anterior leaf of the broad ligament, 3. Ureter identification, 4. Bladder detachment. The learner can navigate between the different *activities*clicking on the chapters displayed on the left side of the screen (A), or on the lower part of the screen. Audio comments (B) synchronized with the images of the intervention describe the *Intervention domain, Actions, goals and anticipations, Rules of action*, and *Operational invariant*. Text appears on the images (C) to show the hidden anatomical structures mentioned in *rules of action* and *operational invariant*. Anatomical boards (D) and explanatory drawings (E) show the actions to be performed and anatomical structures mentioned in the *rules of action* and *operational invariant*.

4.2 The Pedagogical Video

Recording. To create the video, we used footage from surgeries performed by colleagues of one of the co-authors, where patients gave consent for the use of their images for research purposes. We anonymized all images and did not record data that could identify patients. We recorded the endoscopic video feed during the surgical intervention as well as the OR with a Panasonic Lumix LX100 camera. The surgeons were aware of the purpose of the video and did their best to be demonstrative when performing surgical gestures. The entire intervention was filmed from different points of view using the endoscopic camera as well as the outside camera, in order to get a clear view of the entire medical team, but also a zoomed view of the surgical gestures.

Editing. We edited the footage to show the essential elements which were identified when creating the model of the surgical intervention, and show a total hysterectomy by laparotomy (Figure 3). For enabling content navigation, we chose to divide the video into chapters, which lets learners jump in time and choose which segments to see, skip, or re-watch multiple times. Chapters (Figure 3, A) expose the ACTIVITIES, as well as RULES OF ACTION and OPERATIONAL INVARIANTS. Audio comments describe the ACTIONS, GOALS AND ANTICIPATIONS, as well as the RULES OF ACTION and the OPERATIONAL INVARIANT, they can be activated or deactivated (Figure 3, B). The ACTIONS, GOALS, ANTICIPATIONS, RULES OF ACTION and OPERATIONAL INVARIANT are sometimes made salient either through text written on images (Figure 3, C), for example the *Opening of the anterior leaf of the broad ligament*, or through anatomy boards and drawings (Figure 3, D and E), the *Ureter identification* and *Bladder detachment*. The goal is to explicitly show the action to be performed, as well as the underlying anatomical structures which can be injured. The final video is an mp4 file that can be played across devices, with all information flattened into the pixels—there are no layers with objects such as labels. We created one single video because there is no particular value in using multiple videos to answer our research question.

5 METHOD

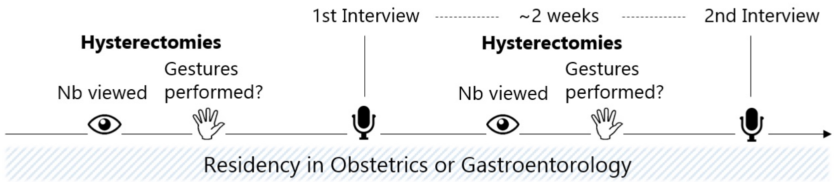
Our goal is to understand the impact of introducing a video with a pedagogical model in the real context of learning.

5.1 Ethical Considerations

The ethics committee of Sorbonne Université approved this study. As the subjects are the medical residents, and not the patients, we did not record any data concerning the patients' clinical history, nor any data or image that could identify them. All participants read and signed (1) consent forms, which explicitly gave them the option to drop out at any time with no reason, and (2) audio-recording consent forms, specifying that interview recordings would remain anonymous and accessible only to the two researchers analyzing the data. Data cannot be linked to participant identities. A list matching participant identities with their anonymized id exists only in an encrypted location different from the data, to which only one of the authors has access. Data was anonymized while coding when appropriate (e.g., removing the name of participants when referring to each other).

5.2 Participants

In total, seven first-year residents specialized in gynecology obstetrics participated in the study. We originally recruited nine participants but two dropped out as clinical activities conflicted with scheduling the second interview, a well-known challenge when conducting studies in the medical domain [8]. The participant table in Figure 4 shows the number of hysterectomies encountered before the first interview and between interviews. All participants nonetheless took part in other surgical procedures through their residency between the interviews.



P1	3	Y	0	N
P2	3	N	0	N
P3	2	Y	1	Y
P4	1	N	0	N
P5	2	N	0	N
P6	4	Y	0	N
P7	5	Y	2	Y

Fig. 4. Overview of participants, including the number of hysterectomies they viewed before the first interview and between interviews, and whether they performed gestures (Y/N).

5.3 Data Collection

Two of the co-authors performed semi-structured interviews in a co-constructive way, as presented by Ellis & Patti [62], two professors in communication whose research interests are personal and collective storytelling, and compassionate communication. Co-constructed interviewing means we sought proposals for answers to the question of how pedagogy, videos, and surgical learning link together in the dialogue between the interviewer and the interviewee and on the basis of the assumption that an interview is a construction.

The semi-structured interviews were performed in an analytical, dialogic and compassionate manner. The interviewers remained open to interviewees' views and desired topics of conversation, as interviewers were learning from the interviewees. Each participant was interviewed two times, at two weeks interval. In between the two rounds of interviews, participants were invited and encouraged to visualize the pedagogical video as many times as they desired. Interviews lasted between 15 and 25 minutes. In the first interview (before watching the video), we focused on: participants' experience with surgery in general and hysterectomy in particular; knowledge of hysterectomy; examples of moments viewing hysterectomies or participating to hysterectomies; training received on hysterectomy; shortages felt in surgical education; and suggestions to overcome these shortages. In the second interview (after watching the video), we asked about the experience with hysterectomy; training on hysterectomy; of moments of association between video and hysterectomy viewed or performed; their general opinion on the video; and the observed difference between the video and training generally received.

5.4 Data Analysis

As we consider that interviews are not only a way of accessing a truth that exists independently, but are rather reality-constructing, we perform a *constructivist* and Thematic Analysis [10] of the interviews. We did not limit the topics discussed during the interview and thus the themes exposed and studied in the results are those that arose in the discussions between the interviewers and the interviewee. The reason for this analysis is that we do not intend to claim universal generalizations of our findings, but rather interpret particular examples and discuss the partial truth they tell about video-based learning for surgery, and the influence of the model that structures the video presented in this article on the participants' perception of their knowledge on the procedure, the value they place on videos for learning about surgery, their perceived efficiency of practice-based learning.

To define the themes, two researchers analyzed the interviews repeatedly, each time increasing the degree of granularity. First, each researcher independently listened each interview to write down categories that could become themes. They met repeatedly to discuss differences and clarifying their views, expanding each others' analyses. They *constructed* together drafts of possible themes in these discussions using their different analyses. Then, the first author listened to the interviews a second time, to confront the drafted themes distinguished with the data, and verify that there were no pieces of data that did not fit within these themes. In a second round of discussions between the researchers, we re-visited and expanded the themes to include all of the data.

6 RESULTS

Our results contribute to understanding the intricate interactions between learning through videos and physical guided training, for early-career residents. Our overarching theme is that *pedagogical videos go beyond enabling the acquisition of its content, they induce a change in learning in other contexts, namely physical guided training*. We establish three themes from our data. Firstly that (1) watching the pedagogical video enabled residents to elicit the limitations of guided practice, namely that rationale is not always made explicit. Secondly, that the video is complementary to guided practice in two ways: (2) on the one hand, when encountering in guided practice the same content as observed in the video, the video makes the rationale explicit, preparing the learner for future observations and helping elicit meaning from past observations. (3) On the other hand, when encountering situations different than those on the video, the video still contributes to understanding such content, as some participants were able to appropriate the video by identifying unexpected relations between its content and their own learning experience from other interventions. With these results, we then discuss how the *ontological* nature of the video enables its strong complementarity with guided physical training, but also how the fact that it is static and linear limits how learners can fully integrate the pedagogical model into their complex learning path.

7 PEDAGOGICAL VIDEOS ENABLED LEARNERS TO ELICIT THE LIMITATIONS OF GUIDED TRAINING

Participants integrated the pedagogical video as a learning resource to their periodic OR visits during their residency. Watching the video while also observing and performing in a real surgical training context, elicited learning issues rooted in the intrinsic nature of guided training in surgery: *performing* gestures while *teaching* how to execute them. We first present these issues as they contextualize our following set of findings on the intricate relation between both types of learning.

7.1 Learning the Rationale Behind Action is Challenging in Guided Practice

Participants reflected on the limited amount of explanations during guided practice, thus failing to understand and learn the rationale behind action: why experts choose to perform them, and why in a particular way—i.e., what are the RULES OF ACTION guiding the gestures and the CONTROLS needed to verify they are being performed correctly. We identify two main reasons from their accounts: first, there is limited time to explain the reasons behind surgical gestures, as this task is time-sensitive and involves high stress. Second, experts automatize routine gestures and typical parts of manual work, thus they fail to systematically judge necessary, or simply remember, to explicit reasoning. P7 specifically mentions these two reasons:

"No, you could not learn everything in the OR because there is the time constraint, which means that even if the attending surgeons try to explain as much as possible, there are always things that they do not explain and that seem logical to them because they have done it 500,000 times and that in fact for you it is not logical. [...] It is not possible to learn everything in the OR." - $P7_{Int2}$

7.1.1 OR Constraints: Limited Time and High Stress. Participants expressed that oftentimes experts lacked the necessary time to explain their actions during guided practice (P7$_{Int2}$, P6$_{Int1}$, P5$_{Int2}$). Indeed, time is of essence during surgery as the primary purpose is to provide patient care, and longer time under anesthesia is correlated with more postoperative complications [14]. Therefore, learning can quickly become second nature as time is allocated to the patient.

On top of time constraints, medical residents expressed that the stress level can be too high to learn efficiently and integrate explanations regarding the rationale of actions. Stress is part of the OR as actions have high stakes with consequences on the life of a person [39]. Still, stress can lead to attention division, prioritising focus towards the task at hand (technical knowledge), and less so on understanding what one is doing and why. Under stress, the breath of attention and the thought processes are narrowed which makes the OR an imperfect environment to learn [71]. The residents play an active role in the task, having to correctly anticipate the expert's needs and gestures—even when exclusively observers they are still more active than when watching a video. The need to pay attention to small but numerous elements hinders learning, as it is difficult to take a step back and reflect on the global understanding of the intervention, as P5 remarks:

"But when you are in the OR, you may be more stressed, you are there without being there and you concentrate a bit on things and you forget steps." - P5$_{Int2}$

7.1.2 Expert Constraints: Automation of Actions. The other reason for the lack of explanations relates to the inherent nature of being an expert. Participants recalled guided training moments where experts invited them to perform gestures as a way of teaching, by providing a series of instructions. Although great opportunities to learn how and why to perform surgical gestures in a specific way, the rationale behind the gestures was overlooked. This rationale comes into the foreground when the expert realizes the learner is incorrectly performing an automatized action. P6 speaks about this when reflecting on the hysterectomies they have participated to as an assistant before watching the video:

"It is true that, for example, if [the expert] holds her scissors in one direction rather than the other, she will not necessarily say 'I am holding my scissors in this direction because' [...] if she gives me the scissors in my hands and I do not do it right, she will say 'no, you have to hold it in this direction' [...]. But I would not necessarily have known in advance because I had not been told before. And afterwards, regarding the stages too, when she advances in the surgery, when she goes from such and such gesture to such and such gesture, she does not necessarily think that she needs to specify what she is doing, she will not necessarily do it." - P6$_{Int1}$

The model enabled participants to elicit the mental processes that occur during guided physical practice—the RULES OF ACTION that implicitly guide the work, and the INFORMATION GATHERING and CONTROLS, actions performed to verify the state of the world before performing the gesture—which may no longer exist in the expert's conscious mind because they have been automatized (P7$_{Int2}$), and do not exist in the learner's mind either because they are not explained (P6$_{Int1}$).

7.2 A Social Vicious Circle: Less Understanding of Rationale Leads to Greater Restrain in Asking for Rationale

Not being able to understand what is happening and why it is happening in the OR has broader social consequences, as the amount of knowledge each person possesses relates to the power relations within team members in the OR. Knowledge becomes capital when climbing the social ladder and establishing one's position among colleagues. Participants manifested that not knowing leads to holding back when it comes to asking questions, as questions are a way of admitting lack of knowledge, and this can negatively impact the resident's position within the complex power structure of the OR. This fear negatively impacts learning, as it adds friction to knowledge acquisition in guided practice. P3 describes how it feels to not know and having to ask:

"I ask questions to the surgeon, but sometimes there are questions that you do not dare to ask, you say to yourself that it is a stupid question and you do not want people to think that you are useless, so sometimes you do not ask the question and then you do not really know." - $P3_{Int1}$

Moreover, we heard from participants how not knowing contributes to shaping how residents see themselves and their role in the OR. As experts instruct to perform gestures, the absence of explanations on the *how* and the *why* of the gesture leads to residents seeing themselves as "technicians", "service providers" that are only used to perform the surgery and not consulted nor listened to.

"For example, even if he [the expert] tells me 'now we're doing this gesture', it would be nice if he could tell me 'we do this gesture and not that gesture for such reason'. And then, 'if we did that, it would do that', that he explains the reasons and not just that we are the technician of the operation." - $P6_{Int1}$

Without knowing the reasons underlying the gestures, the RULES OF ACTION that $P6_{Int1}$ described as *"if we did that, it would do that"*, learners are unable to gain proficiency, and as a consequence they feel left aside. The video sheds light on a specific facet of guided physical training, which is the fact that medical residents sometimes do not dare to ask questions about the implicit reasons guiding the actions (i.e., the RULES OF ACTION) to avoid showing that *"[I] do not know"* ($P3_{Int1}$), which exacerbates the problem of the lack of explanations. Given that there are limited opportunities to exercise learning by direct observation, these issues strain an already burdened learning system.

8 HOW VIDEO-BASED LEARNING AND GUIDED PHYSICAL TRAINING COMPLEMENT ONE ANOTHER

The discussions held during the two rounds of interviews on video-based learning for surgical education also contributed to eliciting another important component of the learning process: the realism of video. The similarity of the images seen on the video with those seen during the practice-based learning facilitates the transfer of knowledge acquired during video-based learning to practice-based learning. About the realism of the video, and the absence of realism of other learning material, P3 mentions:

"You visualize things better. Yes, you understand better. You visualize better what is going on than when you just have a text where they tell you that they are going to dissect such ligament, and then you do not even really know exactly what the ligament looks like. Because you have been told that it is inserted at such and such a place. But if you cannot see it with your eyes, it is complicated." - $P3_{Int1}$

Because of its realism, but first and foremost because of its content and how it is structured, the video explains and shows knowledge on the guided physical practice that enables a better understanding of the activity in a real learning context, while the guided physical practice builds this knowledge but also raises interrogations that can be answered by going back to the video.

8.1 Videos Can Both Prepare for and Elicit Meaning From Guided Training

The participants found overall great interest in the video, which let them better understand the procedure, the decision-making process and their role as an assistant than without the video. As $P3_{Int1}$ mentions, this knowledge is better understood than when reading books, because in books the way in which anatomical structures are represented is very different than the reality, where true colors, aspects and shapes diverge from the anatomical representation on paper. Participants recognized the pedagogical video as an efficient tool in the learning process, as they can access it repeatedly and without stress (P5$_{Int2}$), before and after observing experts practice live in the OR (P6$_{Int2}$). Most importantly, they noted how the video complements the knowledge acquired during guided practice, as it provides rationale, i.e., the *why* and the *how* of the surgical gestures (P5$_{Int2}$, P6$_{Int2}$, P2$_{Int2}$), the elements of the human learning model which enable to access the invisible parts of the surgical decision and gesture, the mental activity and decisions that guide it: RULES OF ACTION and OPERATIONAL INVARIANTS, as well as the implicit parts of the gesture, the GOALS and ANTICIPATIONS, INFORMATION GATHERING and CONTROLS. Without these explanations, *"we are completely blind. [...] It is very difficult to do a representation of what you see in the picture actually. It is very important to know the anatomical references"* (P2$_{Int1}$). We identified two particular ways in which the video complements practice-based knowledge: prospectively (upcoming surgeries) and retrospectively (previous surgeries).

8.1.1 Prospective Effect on Practice-Based Learning: Preparing. Participants explained that the pedagogical video had a prospective effect, it prepared them to what they later observed in the OR by providing theory of the intervention, for example its steps (P3$_{Int2}$), the correct exposition to perform certain surgical gestures (P6$_{Int1}$), or the way to correctly perform the gestures (P6$_{Int2}$). In particular, the video prepared them to *identify actions* during guided training. The video gave them the feeling of having already seen the intervention once, as opposed to discovering it completely when encountering it for the first time in the OR. P3, who participated in further hysterectomies after watching the video, sees the video as theory that complements what comes later in the OR:

> *"Yeah, I find that the video, in fact, it is halfway between theory and practice. Because you have all the theoretical part of 'we do it in such order' and 'you have to pay attention to that', etc. But at the same time, you still have this almost practical part in the sense that you see, you see the key steps at the moment when they are described [...]. As time goes by, it becomes clearer."* - P3$_{Int2}$

The video also prepared learners to *anticipate action*. At the stage of the participants' curricula when the study took place, experts already expect residents to be able to anticipate their gestures, in order to find the right exposition of the surgical scene so that the expert can perform a surgical gesture. P6 explains this by clearly separating the operator, who needs to *know* and the resident who needs to *anticipate*.

> *"I think that it is the operator who needs the most to know, to know the steps because the helper at the end, he is only following. As the helper, you have to anticipate the operator's gestures. Clearly, when I was holding the forceps, I did exactly what the surgeons told me to do. So, I do not know if it would have changed anything for me to have reviewed or not. And so, I think actually, everybody, whether it is the assistant or the operator, we need to know what is going to happen, for the smooth running of the intervention."* - P6$_{Int1}$

This comment can seem contradictory, but it actually provides important elements in the understanding of how the concepts described in the video—derived from the model—can change the course of the intervention. P6$_{Int1}$ mentions being fully guided when performing a gesture, and that therefore they would not have needed to know more about it to do it properly. Still, they also indicate that *"for the smooth running of the intervention"* every member of the medical team should be able to anticipate what is going to happen next i.e., to know the ACTIONS, GOALS and ANTICIPATIONS. After viewing the video, P6$_{Int2}$ complements their statement, when asked about why they would, as they mentioned they did, watch the video several times: *"[If I watched it several times] I could know which step will follow what. [...] Yes, it will always be interesting to review how to do each part properly. At each part, how to do it right? The ligation of the uterine pedicles, how to do it? And where to cut which ligament?"*. Here, P6 confirms that first, the video enables anticipating when training in the OR, and second, to understand *how* to perform correctly, without making errors. The video plays that role because the model enables to retrieve this overlooked knowledge. By defining categories, by standardizing the description of a complex and multidimensional surgical gesture (i.e., guided by knowledge, decision making and fine dexterity), the model makes it possible for learners to understand and acquire this knowledge. The learners do not need to know the model, its categories nor their definition. This model is a tool for the content creators to structure knowledge in a way that is complete and easy to understand for the learners. In the words of the medical residents: *how, why, what* ($P6_{Int2}$) to do in a surgical intervention.

The prospective effects of the video are subject to how the video integrates to the curricula of the residency learning program, as one participant brought up. Motivation is key to make the most of the video. As $P4_{Int2}$ noted, future guided practice opportunities have a focus too far from that of the video, there is a lack of motivation to parse and understand the video content. Indeed, practicing is learning, as well as directly observing others performing surgical gestures practice and being a part of these gestures: having to understand and anticipate. P4 foresees that in the near future they will not take part on hysterectomies, and so the knowledge in the video is not needed, neither it can be structured, i.e., given a purpose:

"I would say that I had a little trouble with this video [...]. So I think that the next 6 months, no, I will not really do [a hysterectomy] [...]. This is not the right time for me [...]. It is probably not the priority here, the hysterectomy." - $P4_{Int2}$

This testimony illustrates how it is important to consider the participants' need in designing a video-based training: they do not need training on hysterectomy and even less by laparotomy in their residency, so they cannot spend time on this video, as informative as it may be.

8.1.2 Retrospective Effect on Practice-Based Learning: Eliciting Meaning. During the second round of interviews, participants mentioned that watching the video brought them back to previous guided practice learning experiences involving hysterectomies. The video provided an opportunity to progress in their learning, both by increasing and correcting their knowledge. The *increased knowledge* comes from understanding actions that at the time learners could not assimilate, even if the expert explained the rationale.

"And so, yes, that is why the video has a good effect to say in retrospect 'here I did that'. [...] when we are taught sometimes, things are explained to us, or they show it by holding our hand and we do not think enough, and seeing the video afterwards it can reinforce a little bit the learning." - $P1_{Int2}$

Watching the video helped residents *understand the reasons* behind a gesture that they performed during previous guided training. This is the case, even when the expert did not explain such reasons during the intervention, even though this rationale is key to determine how to perform the surgical gesture in a specific way. What we observe is that in order to know *why*, residents need to first understand *what* to do, and *how* to do it, two elements that are present in the model behind the video. Specifically, P1 recalls another example, this time about a gesture they had previously done in a laparoscopic hysterectomy, and that the video facilitated understanding.

"When I did it [the gesture], I had a lot of support, I was accompanied in the gesture. [...] I did not think about it exactly, I did not know exactly how it had to be done. I rather followed the movement of the hand that was necessary to perform, so yes, having seen the video, it makes me rethink how I had made the gesture and therefore [...] how it had to be done." - $P1_{Int2}$

Some participants mentioned also *correcting their understanding* after realizing they had misunderstood parts of a previous intervention at the time of guided training. Surprisingly, these previous learning experiences to which videos brought new light, were not necessarily by laparotomy as shown in the video, but laparoscopic. For example, this came to P5's mind when reflecting about a learning opportunity where the procedure was a hysterectomy by laparoscopy, where the video helped to have a clearer understanding of the previously-observed procedure:

"[...] I had a slightly blurred vision of the elements, and now, after watching them many times with a clear head, I visualize better such ligaments, where they are inserted, where they arrive, why do we dissect this, and why do we go this way" - $P5_{Int2}$

The pedagogical video can also lead to *identifying missing knowledge*, needed to fully understand of the procedure. P3 for example, knows that they have to push the scalpel, but parts of how to do this are missing, such as the force needed. During guided practice, they identified that physical elements such as force are important, and later through the video they identify that the amount of force to apply is a hole in their knowledge. This knowledge is not present in our model, thus in the video, as arguably force can only be experienced during the physical performance, through the activation of the sensory-motor experience of the activity, although they can also be considered as GOALS and ANTICIPATIONS, and described as indications of force, location and direction.

"In the video, the rather practical things like 'push your scalpel in this way', 'pull correctly with this clamp rather than that one', all that, it is not precise. I think it is a little bit precise, but not much more in the video." - $P3_{Int2}$

Finally, the video also appears as a way to *complete guided practice* as it provides elements that are not mentioned during guided practice towards the understanding of what was done (because of lack of time, stress, or experts gesture automation), that P2 calls it the *theory* as opposed to *technique*:

"I think it is the video that brings it [the theory] because they do not necessarily tell us the name of the steps, similarly, they say 'here you do like this, you do like that' but, similarly, that it is not very theoretical, it is more technical stuff that they give us as advice, and not really theoretical stuff. And given that we do not have any lectures on that, I think that the video has done this work." - $P2_{Int2}$

These different statements show how the video retrospectively elicits the explanations that are not understood during guided practice.

8.2 How Guided Training Shapes Knowledge Construction From Video Content

Participants used the experience acquired through guided practice to *make sense* of the knowledge acquired through the video. Through participants accounts, we find that the amount of experience acquired during guided training shapes the process of constructing knowledge from the content in the pedagogical video. Being exposed to the pedagogical video and guided physical practice results in a range of ways to construct knowledge, from the ability to identify dents in resident's own knowledge and thus the will to search for the missing bits of information, to the ability to make sense of and structure elements including actions, decisions, and the expected assistance in the OR. In this vein, lack of exposure to guided physical practice can lead to the inability to interpret the content of the pedagogical video ($P4_{Int2}$), as there is a lack of need (thus lack of motivation) to learn about the procedure at the specific moment when training occurred.

Watching the video alone does not guarantee the acquisition of all the elements that are crucial to the learning process. The learning path throughout the residency impacts how the learner experiences the video. The upcoming topics and content of guided practice opportunities can lead to underestimating the benefit of the video, thinking that there might not be a purpose, and reduce motivation to put the effort. For example, P4 had only seen one emergency hysterectomy before participating in this study, where they could not develop a mental representation of the intervention because of the urgency and severity of the procedure. The risks of this urgent intervention requires full attention, leaving no room to focus on anything else than what was vital to the patient, *"to stop the bleeding"*, such as structural aspects of the procedure:

"[...] if I really had to describe exactly in which direction, in which order we did this, the ligatures, that, and why we made such a decision, 'could we have left a piece of the cervix or not?' I did not ask myself on the spot, [the only objective] was just to stop the bleeding. I admit that it was not quite pedagogical. It was a bit beyond that." - $P4_{Int2}$

As a consequence, almost no knowledge was acquired from the video. The need for proximity between practice and training is true for any activity, to arouse not only motivation for learning but also acquisition and retention of knowledge. However, it is especially true during medical residency, when learning is intense, time is short, and responsibilities are high.

8.3 Learning Counterparts: One Learning Strategy Creates the Need For the Other

As guided practice and learning through video complement each other, alternating between the two works in synergy. Both broaden knowledge, one helps produce meaning, and the other shapes how knowledge is constructed as P6 explains, who found that the video on hysterectomy helped them understand how to perform some parts of the C-section:

"Yes, because that is how you correct yourself when you make a gesture in a C-section, and if the operator does not say anything, it means that it was not that bad. Well, first of all, it lets you correct yourself. Then, if I go and look at the video and I see: 'well yes, indeed, they do it rather like that', the next time [I am an assistant] I will concentrate on doing it more like this." - $P6_{Int2}$

P2 also describes how practicing and going back and forth between live experiences and the video will help them learn in the future, after seeing 3 hysterectomies without performing gestures:

"The more I will progress the more I will be interested in different things on this video. I find it is made to be seen several times as we progress, because for the moment I was taking it a little bit in an informative way but after I have seen it several times it will be: 'why do we put the thing [clamps] like that?', 'how do we do it'. I find that we have a different understanding of the video as we progress." - $P2_{Int2}$

Going to the OR shifts the understanding of the video and enables further understanding and learning about already-seen content: in addition to the steps (*what*), the *why* and the *how (*$P5_{Int2}$, $P6_{Int2}$, $P2_{Int2}$) behind them. Identifying knowledge gaps nurtures the need to fill it in one source, by actively seeking knowledge in the other source, encouraging active learning.

While the video appears to put a light on the knowledge that remains inaccessible—because it remains untold—in the OR, the *consolidation* and *integration* of this knowledge takes place in the OR. Indeed, about learning in the OR, $P5_{Int2}$ says it: *"consolidate[s] the knowledge learnt before and then [helps] to really integrate it so yes it is in the continuity in my opinion of the theoretical knowledge"*. Seeing the action performed or taking part in the performance in the OR, after viewing the video, gives action a meaning and a purpose that is not only purely conceptual and theoretical. These considerations must be put into the context of learning for medical residents: their presence is required in the "field" for many hours, to analyze and work on the resolution of numerous and varied situations, both inside and outside the OR.

9 APPROPRIATING THE VIDEO: THE UNEXPECTED IDENTIFICATION OF OPERATIONAL INVARIANTS

As our study integrated the pedagogical video in real learning settings, some residents encountered different techniques for the same intervention shown in the video, or different operations all together, between the two rounds of interviews, showing benefits of the video across techniques and interventions (P5$_{Int2}$, P4$_{Int2}$, P6$_{Int2}$). Participants appropriated the video in ways we had not expected, as we purposefully focused the video only on open hysterectomy. Participants who did not encounter the same intervention from the video in practice-based learning, still made connections with ACTIVITIES, therefore identifying OPERATIONAL INVARIANT. The ACTIONS, GOALS, ANTICIPATIONS, and RULES OF ACTION that enrich already-mastered concepts constitute knowledge that lets learners *"generate, consciously or unconsciously, rules of actions, actions and anticipations"* [82] related to every particular situation, or field of activity. Here, they learned by being able to navigate between different surgical interventions during which identical conceptions are used, but in different contexts.

9.1 Operational Invariants Across Techniques of One Intervention

Some participants mentioned during the second round of interviews how they identified similarities between the hysterectomy by laparotomy, as presented in the video, and by laparoscopy they encountered. In doing so, they appropriated the video to create their own learning scenarios. Participants generated and enriched concepts (such as hysterectomy) by drawing parallels with already-known activities, encountering them in a different context with different ACTIONS, GOALS, ANTICIPATIONS, and RULES OF ACTION that apply to the ACTIONS. P5 analyzes clearly the similarities and differences between the two techniques for the same intervention, and how identifying similarities contributed to learning:

> *"I think that the structures remain the same [between laparoscopic and open hysterectomy]—it is not the same angle firstly, it is not the same vision exactly, but in itself, it remains the same steps in more or less the same order but with the same structures. So, I think that yes, it will help me to better visualize the anatomical structures."* - P5$_{Int2}$

P5$_{Int2}$ is mentally creating OPERATIONAL INVARIANTS between the laparoscopic hysterectomy and the open hysterectomy, which do exist but were never made explicit in the video nor in guided practice. As some of the medical residents in our study had participated in laparoscopic hysterectomies before watching the video, they had acquired part of the knowledge that constitutes the categories related to hysterectomy, i.e., ACTIONS, GOALS ANTICIPATIONS, RULES OF ACTION and OPERATIONAL INVARIANTS. When they watch the video, participants are then able to extend these categories with novel knowledge. Rather than facilitating the *creation* of categories, the video engendered the *enrichment* of categories previously identified during guided practice such as *"the steps"*, the *"[anatomical] structures"* as P5$_{Int2}$ mentions. However, P5$_{Int2}$ also explains that other categories differ, namely the *"angle"* and the *"vision"*. These categories are just other names for the model categories: changing the *"angle"* for performing a similar gesture in a laparoscopic hysterectomy or hysterectomy by laparotomy, means changing the GOALS and ANTICIPATIONS for performing the same ACTION. Together with these changes, the RULES OF ACTION also change as well as their associated INFORMATION GATHERING and CONTROLS. Every time a category is encountered during practice and with slight differences in the video, the multidimensional definition of concepts is enriched. Identifying these variations in the definition of a concept and its categories is part of the learning process. Learners augment their knowledge by being able to differentiate categories which apply to a concept, across all situations or field of activity.

9.2 Operational Invariants Across Different Interventions

Participants in our study also identified similarities and differences between the same ACTIVITY performed in different interventions: C-section and hysterectomy by laparotomy ($P4_{Int2}$, $P6_{Int2}$). We observe this at different levels of tasks, from entire surgical steps to individual surgical gestures. Regarding surgical steps, OPERATIONAL INVARIANTS can exist to prepare for the distinct steps that make the intervention, notably when different interventions involve similar steps. For example, P4's residency did not involve hysterectomies, as shown in the video, but rather C-sections. Although they did not show interest or understood most of the video as their daily practice involves a different intervention (performing only one emergency hysterectomy), they identify an ACTIVITY presented in the video while performing a C-section, the step of bladder detachment:

"Yes, where it was a bit useful to me, and, I found it interesting, was the bladder detachment part, because we do a bit of that in C-section. And I found it funny to have a rather more surgical approach, because in C-section it is a bit 'the bladder bothers us, get rid of'. But yes, it was a little more detailed [in the video] [...] it was interesting." - $P4_{Int2}$

The other time where we observe the identification of OPERATIONAL INVARIANTS, is in specific and concrete surgical gestures. P6 for example made this connection in the ACTIVITY of incision:

"Since I saw the video, I have not done a hysterectomy. But I have done C-sections, and as the video details the Pfannenstiel, I used it for the C-section. It helped me during the C-section." - $P6_{Int2}$

Learning occurred as the participant effectively navigated between different surgical interventions that involved identical conceptions, although they encountered them in different contexts, each with their own GOALS AND ANTICIPATIONS, and RULES OF ACTION.

10 DISCUSSION

This work explored the introduction of a pedagogical video, where the content was created and structured according to the Conceptual Fields Theory, into the larger learning curricula of surgery. We observe that the video has an intricate effect on the other learning opportunities of this curricula, namely guided physical practice—learning side-by-side with an expert. Participants not only were able to extract the video content, but this structured content gave them a frame to better capitalize on their lived experiences when being trained by experts. Our study thus shows that video is a powerful learning tool when created using a pedagogical model, and that video can be an effective adjunct to the golden standard of apprenticeship. It is especially important given that accessing this form of physical guided training is becoming more and more limited. This limitation comes from the changing practice environment due to resident work-hour restrictions (resulting in fewer opportunities to observe surgical practice) [20], the changes in the realities and legalities of the business of medicine (changes in reimbursement and other insurance and medico-legal issues) [5] and the shift in practice pattern [22]. These reasons lead to the development of competing models for learning [67], where video can have a major contribution.

To put our results in perspective, we first discuss how experts overlook explaining why action is performed during guided practice and its consequences to learning. Then, we discuss how providing the why through video benefits learning in guided practice, both directly, by providing scaffolding to understanding action, and indirectly, by facilitating the crossing of social boundaries.

10.1 Overlooking the 'Why' During Guided Action

Our first result shows how guided training is not particularly well-suited for exposing rationale—the *why*–behind expert action. This echoes previous observations of the same phenomena, such as Prentice when noting that experts have a hard time expliciting action as *"instruments, such as scalpels, scissors, and probes, act as extensions of her hands and that the physical sensations of surgery* *are relatively transparent to her when all goes smoothly"* [66]; and also Vergnaud's observation when Ariane space launchers experts (12 to 15 years of experience) were asked to write methodological guides for novices, and *"they gave an almost purely sequential vision of their activity (we do this, then that...), leaving out the reasons for their choice, and the conditional reasoning which accompanied them"* [84], making it impossible for novices to reproduce actions. This is because as experts master a complex activity, they interiorize reasons and automatize actions in order to focus on sophisticated aspects, such as making decisions. It is effortful to bring these interiorized and automatized parts of surgical gestures to the foreground, thus it happens that experts do not consider necessary, or simply overlook, to explicit the reasons behind their decisions. This phenomenon is also known as the *Expert Blind Spot* (EBS) [57] according to which great domain expertise leads to experts making assumptions about the learners, which can be in conflict with the learners' performance and development. Therefore, domain knowledge should be supplemented by pedagogical knowledge, in order to avoid expert-based inferences on students that are at odds with the learning process.

What we observe, in terms of the Conceptual Fields theory, is that RULES OF ACTION, INFORMATION GATHERING and CONTROLS are not systematically explained to residents. This is because experts can sacrifice cognitive resources directed towards explaining, as their primary goal is to carry out action effectively, in a timely manner and prioritizing patient safety. From the assistants' perspective, although their main concern is to assist the expert in this goal, they still need to understand what they are doing and why, given that they are learning. This requires understanding why things operate the way they do, to better determine how to solve problems that arise, by reasoning and inferring what steps need to be taken [42], a cognitive process in itself. It is therefore difficult to carry out both these processes at the same time in the OR, providing care through performing action and learning to perform such action. What our study shows is that videos can be effective adjuncts to apprenticeship by contributing to provide the rationale behind action.

10.2 Using Human Learning Models for Video Benefits Learning During Apprenticeship

Although there is a large body of literature on video-based learning, using human learning models for structuring video content is only recently starting to be explored. Our results contribute to this emerging literature, adding direct and indirect benefits of this approach.

10.2.1 Direct Benefits: Facilitating Understanding Content. We see three direct benefits to learning. **First**, expanding on the notion that videos are effective for learning the content present only in the video itself. Peahl et al. [63] found that when students watch a video containing concepts of postpartum complications, they increase their knowledge on that topic after their clerkship, but without giving indications of how the video impacted the learning of concepts encountered through other experiences during clerkship. Poquet et al. [65] highlight in their literature review of video for learning, that manipulating the way content is structured and communicated has an effect on how that same content is learned, still, we do not know this structure affects the learning of content encountered in other contexts. Our study shows that structuring content using a pedagogical model improves the acquisition of knowledge encountered during guided physical practice by explaining the rationale behind action, preparing the learner to understand why they perform certain actions. **Second**, expanding on the notion that video is meant to be watched *pre*operatively when used for training. Green et al. [29] posit in their literature review on video for surgical education, that the goal of watching video is to increase knowledge that will be used later in guided practice. Our work shows that watching video *post*operatively can also benefit learning, not only in terms of postoperative debriefing [50], as Green et al. point out, but as a tool that enables giving meaning to past guided practice, and understanding in retrospect the rationale. **Third**, expanding on the benefits of video as an extension of the apprenticeship model. Green et al. [29] discuss that the advantages of video to apprenticeship come from optimizing learning as videos are always accessible (outside operating hours), easily accessible (mobile devices), and give access to rare cases. These benefits are of practical nature, whereas we show that there are actual learning benefits, as videos facilitate the understanding of knowledge encountered in the OR, lowering the cognitive load of understanding a piece of knowledge when encountering it for the first time.

10.2.2 Indirect Benefits: Facilitating the Crossing of Boundaries. An indirect benefit arises from participants mentioning that they feel as *technicians* of the intervention, when they are not explained the reasons behind the decisions and actions in the OR. They do not dare ask questions as they are afraid that these could be perceived as *stupid questions*, a barrier that adds friction to learning. Here, learning is considered a social activity, rather than a strictly psychological one, as in Lave's social theory of learning, *"Knowing' is a relation among communities of practice, participation in practice, and the generation of identities as part of becoming part of ongoing practice"* [46]. Therefore, learning is a process of *boundary crossing* mediated by access to different *communities of practice* [32].

By facilitating questioning, the video increased active participation, acting as a bridge to cross the boundary from a technical assistant to a practitioner in development, facilitating the generation of the attending surgeon identity. This transformation happens first and foremost when residents demonstrate their ability to *belong* to the social world of surgeons—which includes showing confidence and decisiveness [66]. This confidence and decisiveness is improved with the acquisition of knowledge: the greater the knowledge, the easier it is to ask questions, the more trust residents gain from the attending surgeon. Thus, the pedagogical video not only impacts the quantity of knowledge acquired outside the OR, but also the quality of learning inside the OR, making it easier for learners to demonstrate their ability to *belong* to the surgical team. This ability is extremely hard to measure and is determined inside the OR by expert surgeons. Indeed, apprentice surgeons absorb not only skills but also behaviors, values, which can be manifest or latent *"some of which they know they are learning, some of which they learn without realizing it"* [40]: the surgical ethos.

10.3 The Ontological Nature of the Video

We believe these benefits come from the *ontological* nature of the pedagogical video we created. The pedagogical theory we used goes a step further than multimedia design theories [63], instructional videos [11], or cognitive load theories [13, 76, 90] when used as guidance to create pedagogical, or instructional videos. Using human learning models lets content creators structure the pedagogical videos content not only in terms of *how* to present content to learners, but also of *what* to present, taking into account what they learn in their real-life training. The *ontological* nature of the video resides in the fact that, prior to creating the learning material, (the video recordings, the audio comments, the anatomical boards and explanatory drawings) we identified the fundamental components of the task as well as the relations between them: the sequence of ACTIONS composing the ACTIVITY along with the mental reasoning guiding it, the GOALS, ANTICIPATIONS, RULES OF ACTION, CONTROLS and OPERATIVE INVARIANTS. By providing the categories to which the components belong, the model enables learners to integrate theoretical knowledge from the model through reflection of past practice, or by contrasting structured knowledge from the video with real experience. Both with the genuine aim of solving a problematic situation. This meaning-making as a way to assimilate knowledge is described by Huard: *"situational experience is an opportunity to carry out the process of pragmatic elaboration, the process by which a concept acquires meaning for a subject through the situations in which they are involved"* [38]. The gap in learning can effectively be filled through implementing a learning model using video as a medium, and having it *complement*, not replace, guided training, by helping elicit meaning to practice. In contrast, a pedagogical video of *phenomenological* nature is a video where the creation of the learning material precedes the definition of its components, leading to a focus on the sensitive experience of the task, i.e., the sequence of actions that compose the task. This leaves aside the tacit rules and implicit knowledge that dictate the action at every step.

10.4 The Challenges of Producing and Promoting Theory-Based Videos for Learning

Although using human learning models brings benefits to learning, they hinge on the costs of the extensive work required in the process of creation as well as in the cost of promoting this learning tool in surgical curricula. Recording on the one hand is highly time-consuming as filming open surgery is technically challenging: the space to set up cameras in the OR is restricted by the material present in the room, the movements of the medical team, the sterile field, the strong and varying lighting. Moreover, the surgical scene is occluded by the surrounding surgical team, which requires high camera mounts. Editing on the other hand is also time-consuming and requires multiple back-and-forth between images and model, and discussion with an expert in each step [4]. Promoting these videos in a clinical context also presents some challenges which should be considered. Incorporating videos should be adapted to each institution, in a coherent and realistic manner to not impose additional burden to students who already have a high workload.

11 THE FUTURE OF VIDEOS: EFFECTIVE ADJUNCTS TO GUIDED TRAINING

To conclude this work, we go one step further and explore the future of videos as effective adjuncts to physical guided training. From our study, we observe that although videos can be great companions for learning surgery through guided practice, when it comes to implementing a pedagogical model, certain limitations of the medium restrain it from unleashing their full potential. In this section, we first discuss how, although previous work has looked into breaking linearity by enhancing content navigation, the presentation of video content still remains *linear*, in one dimension, and *phenomenological*, with no prior fundamental structure. We posit that the *linearity* and the *phenomenological* approach of video as a medium is what prevents video creators, domain experts, from effectively implementing a pedagogical model. Second, we present our exploration on how to move beyond the *linear* and *phenomenological* nature of videos in a workshop with four expert surgeons, that designed concepts as paper prototypes to address the interactive needs we identified for implementing a pedagogical video.

11.1 Current Approaches to Learning Videos

11.1.1 Content Navigation Remains Fundamentally Linear. Although HCI research has looked into ways to break from the linear navigation of video, the current approach is to formalize steps in a phenomenological way, extracting the sequence of actions that compose a task in a linear timeline and to enable navigation by jumping between steps. This research has focused on techniques for navigating content. *Chronicle* [30] lets users navigate the creation of a graphical document using the history workflow, creating steps that viewers can jump to, and visualize the operations that led to that step (e.g., undo, or layer manipulations). To navigate tutorials, *MixT* [15] automatically generates mixed media tutorials based on user demonstrations, then, users can jump through steps and watch a specific video segment when curious about how to perform a particular step. Truong et al. [78] later introduced hierarchical tutorials, where viewers can navigate makeup tutorials through steps grouped in hierarchies (e.g., eyes, face, lips). To navigate lectures, Shin et al. [73] propose *Visual Transcripts*, and introduce an algorithm that identifies key steps in the creation of a complex math formula, that viewers can navigate to and see the associated lecturer's speech as transcript. Specifically for MOOCs, Yadav et al. [88] propose showing word clouds on a timeline. Only ConceptScape [47] introduces navigation that is non-linear, through a crowd-sourced concept map of an existing video, where users can click on concepts and seek to the corresponding segment.

These work identify key steps in the recorded content to enable navigation, sparing the user from skimming the full footage. Still, navigation is fundamentally restrained to a linear timeline, as steps are presented sequentially one after the other, and the identification of the *structure* is left to the viewer. Viewers thus have little support when adapting their viewing strategy according to where they are in their learning curricula: their knowledge level, their past and future experiences, and other available learning opportunities. For example, if a learner has participated in an intervention they could now benefit from understanding the rationale behind some of the performed actions, however, in a linear content presentation, it is not immediate how to locate the RULES OF ACTION and CONTROLS present in a step.

11.1.2 Content Creation Remains Fundamentally Phenomenological. In the presented literature, authors do not define *ex ante* the task components taught and their relations. The creation of the learning material is not driven by a preliminary work of identification of the elements necessary to understand and to learn the activity, which results in a video that teaches what is intuitively and presumably considered to be the task–often meaning what is visible. Participants specifically explained how important it was to have that implicit and invisible knowledge that the *ontological* approach provides, as $P2_{Int1}$ puts it, they are *"blind"* without it. As advocated by Arghode et al. [1] in their literature review on adult learning theories and online instruction, the learning theories provide a structure and a guiding framework for the creation of learning material. Furthermore, Weibell et al., in a research article on domain-specific theories of learning state that the "*Identification of common principles found in existing theories of learning, as well as those that emerge from experience, may be an important step toward closing the divide between practice and theory*" [86].

Without a theory-based approach, learners can end up viewing content that is of no interest and negatively impact their medical education. As Mayer highlights, medical education should aim at reducing extraneous processing during learning to focus on *essential* and generative processing (aimed at making sense of the material) [52], and *"People do not learn better from a multimedia lesson when interesting but extraneous video is added"* [53]. Hence the great value of any learning material for surgical training that capitalizes on the power of knowledge transmission is the OR, as well as its weaknesses. This incentive is emphasized in Kneebone et al.'s work on the evaluation of clinical simulations for learning procedural skills: "*simulations should map onto real-life clinical experience, ensuring that learning supports the experience gained within communities of actual practice*" [43].

11.2 Workshop on The Future of Videos

After analyzing the data from the interviews, we conducted a workshop with four expert surgeons in gynecology-obstetrics. The goal was to envision *interactive methods of making and consuming videos that fit into real learning during residency* and to *break the linearity: think interactivity and access to information according to the level of the person watching the video.* We carried out three rounds of exercises, where we asked participants first to come up with concepts for creating and consuming videos that break the linearity of play/pause and chapter navigation, and then refine them in two rounds. In the first exercise, experts had to arrange 10 scenes of the same procedure (open hysterectomy), completed by 2 scenes of a different procedure (C-section) where the gestures performed are the same. The arrangement had to be non-linear, for 3 residents of different levels to view, with the goal of making them understand a particularly complex moment. They were not constrained on how to achieve this. In the second exercise, they had to imagine the 3 residents preparing for surgery with the video. For each case, the experts had to describe how the resident trains with the video, for example which parts the residents view, how long does each resident watch the video, what elements will they be likely to miss, how easily can they access the necessary information, how easily can they hide information, among other questions. In the third exercise, the experts had to imagine that each resident went to the OR, observing different interventions (one hysterectomy by laparotomy, one laparoscopic hysterectomy, and one C-section), suggesting ways to improve the effectiveness of the video with the proposal chosen at the end of exercise 2, for example: how to facilitate interaction, access to all necessary information, possibility of not listening or seeing what is not necessary, and the possibility of changing the variable used to access information (gesture variable, or instrument variable).

11.3 Breaking Phenomenological and Linear Approaches

From the workshop, we forge a vision on moving video away from *phenomenological* approaches and linear representations.

11.3.1 Goals. This vision is based on four goals. First, to identify, prior to the creation of the learning material, the rationale behind expert action (GOALS, ANTICIPATIONS, RULES OF ACTION as well as INFORMATION GATHERING and CONTROLS) and integrate it into guided practice experiences, as this is key in surgical learning: *"surgeons must teach both skills and meaning"* [66]. Second, to enable learners accessing a spectrum of concepts categories (GOALS AND ANTICIPATIONS and RULES OF ACTION) at the right time in their residency to let them create their own learning scenarios, from simple to advanced ones, so that the video continues to train the attending surgeon through their apprenticeship. Third, to enable residents to extrapolate knowledge with the goal of identifying OPERATIONAL INVARIANTS across procedures. Finally, to contribute to integrating residents to the social environment. These measures are essential tools in accessing the rationale behind experts' actions that learners must understand to develop skills on the complex activity being learned.

11.3.2 Making Videos with a Ontological Approach and Interactive Navigation. With these goals in mind, we envision moving towards interactive videos with an ontological approach to break the linearity and phenomenological approaches. Through the workshop, we envision that to implement content created using an ontological approach, the media of video should enable defining different information levels, information representations, as well as allow for customization of visible content.

Multiple Information Levels. The possibility to access different granularity of knowledge for one piece of information. A semantic layer transversal to segments could achieve this, such that learners can move downwards towards a more detailed level, or upwards towards a more abstract level, as needed (Figure 5). It is important that video segments signal that there are depths of level available. Levels can encompass various information representations, for example auditory comments or text that augments images.

Fig. 5. Example of information levels. A video timeline has triangles indicating that levels with more detail are available. The learner can access higher detail, which can translate to more video footage visible, or text annotations appearing. On the bottom of the timeline, the participant also drew a timeline representation where all the available levels are collapsed. Depth of information can extend on multiple levels.

Going up or down in granularity does not necessarily mean *more* information, but *different* information, as for example text labels that identify anatomical structure is of interest for novices, but bothersome for experts which easily identify them. The ability to access information at different depth levels lets the learner access the right level as they advance in their curricula. For example, being able to toggle certain GOALS and ANTICIPATIONS, RULES OF ACTION, as they accrue experience and feel ready to understand these knowledge.

Multiple Information Representations. The possibility to access different representations of one single piece of information. Again, a semantic layer on top of segments (Figure 6) could enable learners to access the various representations depending on whether they are about to perform it in an upcoming intervention, or they have already seen it. For example different representations of an image, such as filmed in the OR from inside of the patient's body (views of the uterus or of the ovaries), either anatomical (e.g., vessels and nerves) or intervention-related (e.g., hysterectomy or C-section). Another example is the different ways in which action is performed, such as the level of preciseness (from mastery to error), by using different instruments, or when performed by different experts. Finally, it can be how one surgical gesture is executed in other procedures (hysterectomy vs. C-section), or other variations of the procedure in the video (open vs. laparoscopic). This capacity would support learners to identify OPERATIONAL INVARIANTS i.e., their ability to understand the similarities and differences when performing the same ACTION in different situations.

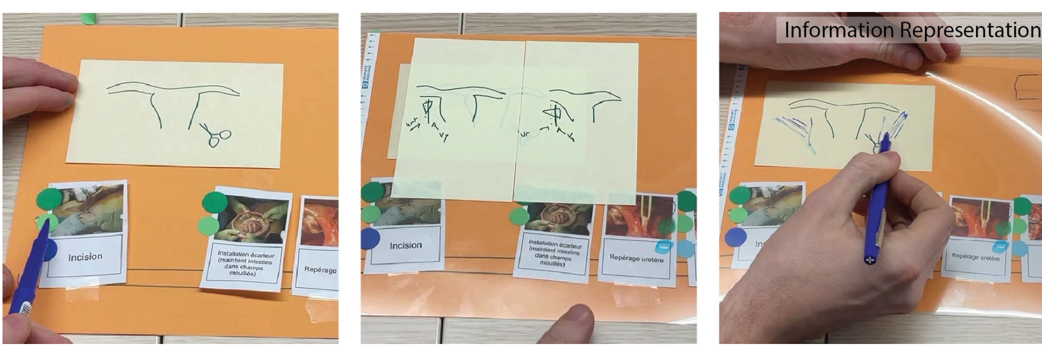


Fig. 6. Example of information representations. A a video player on top shows the current frame, and a video timeline below is composed by visual steps, which include colored circles that signal different representations. Left: the current representation shows a recorded video. Center: the current representation shows two different experienced surgeons doing the same step. Right: a new representation layer is added, showing an anatomical diagram on top of the intervention.

Content Customization. Finally, surgeons stressed the importance of appropriating the content, by hiding segments that might be irrelevant at a certain time in their learning curricula, as well as outdated if they already integrated information at a certain level (Figure 7). Also, reordering segments to visualize information in specific orders, notably seeing the result of performing a gesture before the segments about the actions on how to perform it. Seeking to the result before starting the video is a behaviour also observed in other physical training domains, notably following recipes through video [58]. Customization can include the different representations and levels, for example placing the result of an intervention either schematically or in real detail, before watching the procedure. Customization can be constrained by experts, by selecting only the information they see as necessary for this video, or unconstrained so that learners can chose to access the information when they believe they are ready, based on their previous experience with the activity, the training they have received on it (guided practice, classes, books, simulation), their available time and their learning needs (how much knowledge they want to acquire on the activity). This definition of previous knowledge and desired progression, can condition the level of depth spectrum available in the video, and of the diverse representations.

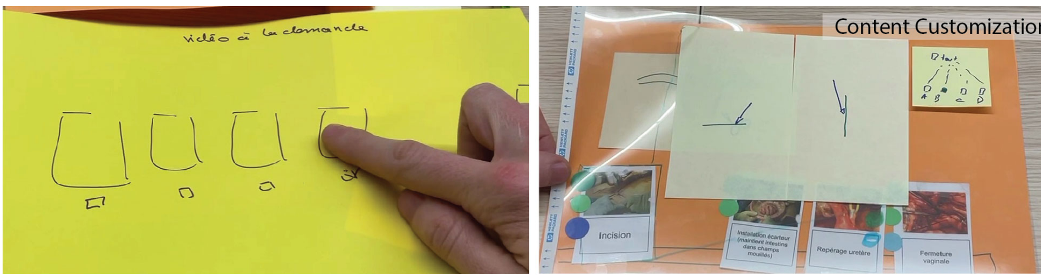


Fig. 7. Example of content customization. The learner chooses what they want to see. Left: the user can select chapters or information representations before viewing the video. Right: the system shows the relations with other interventions (top right post-it), and the viewer chooses to visualize the differences between a particular step of the intervention, and the same step performed in another intervention.

12 LIMITATIONS AND FUTURE WORK

We discuss in this section the limitations of the study and directions for future work.

Methodology and Claims. We chose to carry out the study in an ecological setting, which impacted the number of participants. This number is too small for corroborating hypotheses, but still enabled us to produce insights on the intricacies of pedagogical videos and guided physical training. Also, we only studied first-year residents, and we cannot claim that our claims extend to learning at all stages of the medical career. We encourage future studies to compare and contrast our findings, as well as to extend them by recruiting participants at later stages in the surgical learning curricula.

Demonstrating the Benefits of Ontological and Non-Linear Videos. Our research points towards linear content navigation as a limitation to using videos as adjuncts to physical guided training, however, we do not demonstrate the benefits of other approaches. Future work can build on these results to conceptualize and implement novel video navigation techniques, for example through Augmented or Virtual Reality [25], as well as conduct studies to investigate their impacts on learning. The hypothesis that pedagogical videos created with an ontological approach are more efficient than their phenomenological counterparts, as they are adjuncts to guided practice, remains to be studied. This can be investigated for learning outcomes (is learning improved?) as well as clinical outcomes (is patient care improved?). In parallel, it would also be interesting to investigate if these benefits stand and can be enhanced by making explicit the structure used for organizing content on the videos.

Generalizability. This study focuses on one specific activity which is surgical training. A similar protocol can be applied to a different physical activity, which would bring new insights on the applicability of a pedagogical ontological approach for the creation of learning videos to activities where guided physical training is not as stressful, variable, or where learning is not tied with the simultaneously with a primary activity (the surgical treatment of a patient).

Content Creation. Creating theory-based videos for learning is challenging, as the process is very time-consuming and requires the implication of a pedagogy expert who knows and masters human learning theories. Future work can address this, investigating how to make the process less consuming in terms of time and human resources. One direction is partial or full automation, as existing powerful tools can identify and segment the steps of a surgical intervention, using laparoscopic videos [41], instruments signals and annotations [21]. It is reasonable to think that in the future these tools could be used to facilitate content creation when making a pedagogical video for surgery, by contributing to identifying *physical* processes (i.e., the ACTIONS), *mental* processes (i.e., the GOALS, ANTICIPATIONS, RULES OF ACTION, CONTROLS) as well as the OPERATIVE INVARIANTS), all which constitute the activity of learning surgery and constitute the video.

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A COMPLETE MODEL OF THE HYSTERECTOMY BY LAPAROTOMY

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
Preoperative check	1. Check the identity of the patient: name, first name, date of birth			
	2. Recall the planned procedure (validated with the patient and the team): adnexectomy or not			
	3. On the anaesthesia side: Check that all documents are available (allergy, stop certain treatments, fasting, antibiotic prophylaxis...)			
	4. On the surgical side: Check that all documents are available: imaging, anapathy, conclusion of surgical staff, conclusion of multidisciplinary consultation meeting			
	5. Check the material: A box of adapted instruments, retractors, an electric bistoury, +/- complementary energy: ligasure forceps, other..., bladder probe, fields			
1. Positioning of the patient	1. place the patient in supine position, arms at 90°, double shift position (legs apart)			
	2. Prepare the vaginal cavity with Betadine before starting the surgery			
	3. Incise the peritoneum			
	4. Set up the sterile fields (nipple, pubic symphysis, anterior superior iliac spines laterally free)			
	5. Place an indwelling bladder catheter to ensure constant bladder drainage	Keep the bladder empty. This is important for safety		
	6. Generally, the surgeon places himself/herself on the left side of the patient			
2. Incision and inspection	1. Incise the abdominal wall transversely, 3 cm above the pubic symphysis (Pfannenstiel incision)			
	2. Incise the fascia of the rectus abdominis muscles			
	3. Incise the peritoneum	Be sure to follow the centerline	The midline as well as the longitudinal incision is the standard reference for pelvic surgery, to facilitate the surgical procedure and avoid damage to other vital structures.	
	3.1. Perform a transverse incision			
	4. Carefully lift the intestines and hold them in wet fields			
	5. Install the spacer	Examine the uterus, surrounding organs and check for abnormalities and/or adhesions	Restoration of the pelvic anatomy by release of adhesions is mandatory for a safe operation	

(Table continued on next page...)

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
3. Opening of the peritoneum, exposing the round ligament	1. Place the Kocher clamps	Check that the forceps tip is in the avascular and transparent space of the anterior and posterior broad ligament, and does not reach the uterine vessels below	Usually, Kocher clamps are placed between the uterus and the appendix	
	2. Hold the uterus in traction contralateral to the surg. area	Identify the round ligament		
	3. Grab the round ligament on the right side and lift it using forceps			
	4. Insert the needle twice with 1-0 absorbable sutures			
	5. Tighten and cut between the ligatures with scissors	Identify the starting point for the vesico-uterine incision: lift the broad ligament up and identify the vesico-uterine fold. (Usually the target is 1cm down from the lower end of the uterine serosa). If you locate the target termination point for the incision (i.e., the starting point for the next incision) then you decrease the risk of performing overly deep dissections that can induce bleeding. Be sure to stay superficial in the dissection: if you stay superficial, then you avoid any bleeding.	When cutting ligaments or vessels, it is important to put the scissors perpendicular to the ligament. After sectioning, air will enter the retroperitoneal cavity, the loose connective tissue will fall out, and the cavity will be seen	
4. Opening of the broad ligament	1. incise the anterior leaflet of the broad ligament	Be sure to stay superficial in the dissection. If so, then you avoid any bleeding	Dissections that are too deep into the bladder can lead to bleeding or bladder injury	
	2. Lift the broad ligament upward to identify the vesico-uterine fold.			
	3. Lift the broad ligament with forceps, and detach all subperitoneal connective tissue with scissors		Generally the target is 1cm down from the lower end of the uterine serosa	
	3.1. Perform a peritoneal opening	If the uterus is not very mobile, the peritoneal opening results in greater mobility		When the uterus is not very mobile
	4. Make a concave incision line from the round ligament to the vesico-uterine fossa			
	5. Incise the thin transparent peritoneum to the target			
	6. Continue the incision of the central leaflet of the broad ligament cranially parallel to the lumbo-ovarian ligament			
	7. Pull the peritoneum strongly, then attach the scissors almost vertically to the peritoneum, push lightly and then scrape down all the connective tissue under the peritoneum.	If you methodically carry out these gestures, then only a transparent and fine peritoneum remains which can be incised without bleeding. If the connective tissue is poorly detached, veins and capillaries remain on the peritoneum and the incision ends in bleeding		
	7.1. Perform the same procedure			In case of ureter, bladder, and rectum detachment of surrounding tissue

(Table continued on next page...)

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
5. Location of the ureter and section of the lumbo-ovarian ligament	1. Dissect loose connective tissue and incise toward the lumbo-ovarian ligament			
	2. Identify the ureter		The ureter is visualized on the posterior peritoneal leaflet of the broad ligament. When stimulated with the finger, a “snake-like” peristalsis movement is visualized. The ureter is identified crossing the iliac vessels before any gesture on the lumbo-ovarian ligament. This allows identification of the needle insertion point at a distance from the ureter	
	2.1. The incision of the lateropelvic peritoneum is extended parallel to the lumbo-ovarian ligament.	The external iliac artery is then identified on the medial part of the psoas muscle.		When the identification of the ureter is difficult
	3. Insert the needle away from the ureter			
	4. Ligate the ligament and cut it			
	5. Strongly pull the peritoneum and then attach the scissors almost vertically to the peritoneum, push lightly, and scrape all connective tissue below the peritoneum	Determine the end point of the incision	The termination point of the incision is the uterine origin of the sacro-uterine ligament	
	6. All of the above steps are performed for the left-sided round ligament, the broad ligament, the lumbo-ovarian ligament or appendix			

(Table continued on next page...)

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
6. Bladder detachment	1. Mobilize the bladder: begin mobilization at the midline of the cervix	Before mobilizing the bladder, palpate the cervix from the anterior and posterior sides. If you palpate the cervix, then this will allow you to check its position	The bladder frequently drifts laterally due to fibroids or adhesions. Palpation is also essential to estimate cervical length.Second, mobilizing the bladder prevents bleeding from the lateral vesico-uterine ligaments	
	2. Lift the anterior leaflet of the severed broad ligament		When the surgeon lifts the anterior layer of the broad ligament, the vesico-uterine space opens spontaneously where the first incision should be made, in the center of the cervix	
	3. Push the scissors vertically to the cervix and cut the connective tissue	Identify Halban's fascia. If you push the scissors vertically at the cervix and cut the connective tissue, then this will reveal Halban's fascia. Check for fat. If you encounter fat, then change the route. Encountering fat is the dissection coming too close to the bladder	Halban fascia is white, soft and shiny. The fat belongs to the bladder. Its presence indicates that you are not in the right plan	
	4. Dissect the connective tissue downward using scissors from the cervix completely to the lower end of the cervix	Make sure that the dissection is not hemorrhagic. If the dissection is hemorrhagic, care must be taken to find the correct plane, in contact with Halban's fascia, for an exsanguinated dissection	The bladder is now mobilized to the appropriate height, about 1cm below the vaginal cul-de-sac	
		If you observe bleeding, you are not in the right plane	The vesico-vaginal space is avascular	
	5. Loose connective tissue on the surface of the ligaments is carefully removed			
	6. Place the retractor over the detached portion, pushing the bladder down			
	7. Carefully dissect and remove connective tissue from the uterine artery and vein			
	8. Also remove connective tissue from the vesico-uterine ligament	If you remove the connective tissue on the vesico-uterine ligament, then you avoid ureteral injuries		

(Table continued on next page...)

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
7. Ligature and section of the uterine pedicles	1. Skeletonize the ascending branches of the uterine artery and veins			
	2. Keep the uterus in an upward pull and push the bladder down using the retractor	Feel the ureter running along the posterior leaflet of the broad ligament. If you know the position of the ureter, then you limit the risk of injury	It is possible to identify the level of the ureter that enters the cardinal ligament 1 to 3 cm lateral to the cervix and 2 to 4 cm below the uterine artery	
	3. Cut the cardinal ligament twice including the uterine artery and veins until you reach the vaginal cul-de-sac			
	4. Place a first Jean-Louis Faure forceps, concave upwards at a 90° angle to the upper part of the cervix so that the tip of the forceps arrives 1cm below the height of the internal os of the uterus			
	5. Place a second forceps along the cervix for hemostasis of the small ligament veins	Check that the clamped side of the forceps is outside the surface of the cervix. If the clamped side is outside the surface of the cervix then all vessels will be fully clamped		
	6. The tip of the forceps reaches the level of the vaginal cul-de-sac, then the lower half of the cardinal ligament is cut and sutured	Recognize the plane that demarcates the cervix from the ligament	Once this plane is reached during the section of the cardinal ligament, especially near the utero-sacral ligament, it is possible to feel confident about the cutting. The cut has finally reached the vaginal cul-de-sac	
		Avoid cutting too deep into the paravaginal tissue.If you cut too deep into the paravaginal tissue, it may result in a significant amount of bleeding	To avoid injury to the ureter during the cardinal ligament ligation, the use of two forceps is essential. Each step moves the ureter laterally to the cervix and vagina, which is safer than using only one clamp. The surgeon can feel the course of the ureter at any time during the surgical procedure and should confirm the distance between the ligature and the ureter	
	7. Perform these steps on the left side		Generally, it is not necessary to cut the utero-sacral ligament which will be cut simultaneously during the amputation of the vagina	
	8. Place a vaginal valve or mounted pad in the pouch of Douglas, and palpate the transitional area between the cervix and vagina			
	9. Insert the scalpel vertically into the highest portion of the anterior wall of the vagina			

(Table continued on next page...)

Activity	Actions, goals and anticipations	Rules of action, information gathering and controls	Operational invariant	Intervention domain
8. Vaginal opening	1. Prepare the portio and vagina with povidone-iodine			
	2. Insert a mounted tampon or vaginal valve into the vaginal cavity			
	3. Place the long, straight Kocher forceps sequentially at the end of the vagina for hemostasis			
	4. Cut and tie the utero-sacral ligament with the vaginal wall			
	5. Close the vaginal dome with separate X-stitches at the corners, then separate X-stitches or over of the vaginal slice	Be sure to place the curved forceps along the vaginal cul-de-sac.If the curved forceps are placed along the vaginal cul-de-sac as a landmark, then it is easier to cut the vagina with the scalpel or scissors along the curve of the forceps.Be sure to make a careful suture at the lateral end of the vagina, near the tip of the cardinal ligament.		
	6. Clean the retroperitoneal space with warm saline solution	Confirm the absence of bleeding and foreign bodies		
9. Closing the abdomen	1. Check the gauze count			
	2. Suture the pelvic peritoneum with continuous 2-0 sutures and close it completely			
	3. Remove the retractor and gauze and return the bowel to a normal position			
	4. Close the abdomen by suturing the peritoneum, fascia, and skin			

Table 2. Complete Model of the Hysterectomy by Laparotomy

B QUOTES IN THEIR ORIGINAL LANGUAGE

This appendix contains the quotes throughout the paper, in their original language, French.

Section 7.1

"Non, on ne pourrait pas tout apprendre au bloc parce que, il y a quand même la contrainte du temps au Bloc, ce qui fait que même si les chefs essaient d'expliquer au max, il y a toujours des trucs qu'ils expliquent pas et qui semblent logiques pour eux, parce qu'ils en ont fait 500.000 et qu'en fait pour toi c'est pas logique [...] Ce n'est pas possible de tout apprendre au bloc." - P7_{Int2}

"Mais quand tu es au Bloc, tu es peut être plus stressé, t'es là sans être là et tu te concentres un peu sur des trucs et t'oublies des étapes" - P5_{Int2}

"Donc, c'est vrai que, par exemple, si elle [l'experte] tient son ciseau dans un sens plutôt que dans l'autre, il ne va pas forcément dire 'je tiens mon ciseau dans ce sens parce que' [...] si après il me donne les ciseaux dans les mains et que je ne le fais pas bien, là, il va me dire 'non, il faut le tenir dans ce sens parce que' [...]. Mais je n'aurais pas forcément su à l'avance parce qu'on ne l'avait pas dit avant. Et après, au niveau des étapes aussi, quand elle avance dans la chirurgie, quand elle passe de tel geste à tel geste, elle ne pense pas forcément qu'elle a besoin de préciser ce qu'elle est en train de faire, elle ne va pas forcément le faire" - P6_{Int1}

Section 7.2

"Je pose des questions au chirurgien, mais parfois il y a des questions que tu n'oses pas poser, tu te dis que c'est une question stupide et t'as pas envie qu'on pense que t'es nulle, donc parfois tu poses pas la question et du coup, tu ne sais pas trop." - P3_{Int1}

"Par exemple, même s'il [l'expert] me dit 'la on est en train de faire tel geste', ce serait bien que même après il dise 'on fait tel geste et pas tel geste parce que telle raison'. Et puis, si on faisait ça ça ferait ça, qu'il nous explique les raisons et pas juste qu'on soit le technicien de l'opération" - P6_{Int1}

Section 8

"Tu visualises mieux les choses. Oui, tu comprends mieux. Tu visualises mieux ce qui se passe que quand tu as juste un texte où on te dit qu'on va disséquer tel ligament, et tu sais même pas vraiment exactement à quoi ressemble le ligament. Parce qu'on t'a dit qu'il s'insérait à tel et à tel endroit. Mais si tu ne vois pas tes propos yeux c'est compliqué." - P3_{Int1}

Section 8.1

"on est complètement à l'aveugle. C'est hyper difficile de se représenter ce que tu vois sur l'image en vrai. C'est très important de connaître les repères anatomiques." (P2_{Int1}).

"Ouais, je trouve que la vidéo, en fait, elle est à mi-chemin entre la théorie et la pratique. Parce que tu as toute la partie théorie de 'on fait dans tel ordre', 'il faut faire attention à ça', etc. Mais en même temps, tu as quand même cette partie un peu presque pratique au sens où tu vois, tu vois les étapes clés au moment où on te décris." - P3_{Int2}

"Je pense que c'est l'opérateur qui a le plus besoin de connaître, de connaître les étapes puisque l'aide au final, il a plus qu'à suivre. En tant qu'aide, il faut quand même anticiper les gestes de l'opérateur. Moi, clairement, quand je tenais les pinces, je faisais au millimètre près ce que les chirurgiens me disaient de faire. Donc, je ne sais pas si, de toute façon, ça aurait changé quelque chose que j'ai révisé ou pas. Et donc, je pense qu'en fait, tout le monde, que ce soit l'aide ou l'opérateur, on a besoin de savoir ce qui va se passer pour pouvoir, pour le bon déroulement de l'opération." - P6_{Int1}

"[si je le regardais plusieurs fois] j'aurais pu dire pour savoir quelle étape va suivre quoi. [...] Si, ce sera toujours intéressant de revoir comment bien procéder à chaque partie. À chaque partie, comment

bien faire? La ligature des pédicules utérins, comment le faire? Et où bien couper quel ligament?" - $P6_{Int2}$

"Je dirais que j'ai eu un peu de mal avec cette vidéo [...] Donc je pense que les 6 mois qui suivent, non, j'en ferai pas vraiment. [...] Ce n'est pas le bon moment là pour moi [...]. C'est sans doute pas la priorité là l'hystérectomie" - $P4_{Int2}$

"Et du coup, oui, c'est pour ça que la vidéo possède bien un effet pour un rétrospectivement se dire 'là j'ai fait ça'. [...] quand on nous apprend parfois, on nous explique des choses, ou alors on nous montre en nous tenant la main et on ne réfléchit pas assez, et en voyant derrière la vidéo ça peut renforcer un peu l'apprentissage." - $P1_{Int2}$

"Quand je l'ai fait [le geste], j'étais très très épaulée, on m'a accompagné dans le geste. En faisant le geste je n'avais pas réfléchi exactement, je ne savais pas exactement comment il fallait le faire. J'ai plus suivi le mouvement de la main qu'il fallait faire, donc oui, avoir vu la vidéo, ça me fait en effet repenser à comment j'avais fait le geste et du coup, [...] comment il fallait faire." - $P1_{Int2}$

"[...] j'avais une vision un peu floue des éléments et là, de revoir plusieurs fois à tête reposée la vidéo, je visualise mieux tel ligaments, où il s'insèrent, où ils arrivent, pourquoi on décolle ça, et pourquoi on va par là." - $P5_{Int2}$

"Dans la vidéo, les trucs un peu pratiques genre 'pousse ton bistouris de telle manière que celle ci', 'tracte bien avec telle pince plutôt qu'avec telle autre', tout ça, ce n'est pas précis. Je crois que c'est un peu précisé, mais pas plus que ça dans la vidéo." - $P3_{Int2}$

"Je pense que c'est la vidéo qui l'apporte [la théorie] parce qu'on ne nous dit pas forcément le nom des étapes, pareil ils disent 'là tu fais comme ça, tu fais comme ça' mais, pareil, c'est pas très théorique, c'est plutôt des trucs techniques qu'ils nous donnent comme conseils, et pas des trucs vraiment théoriques. Et vu qu'on n'a pas de cours là dessus je pense que la vidéo elle a fait ce travail là." - $P2_{Int2}$

Section 8.2

"[...] si je devais vraiment décrire exactement dans quel sens, dans quel ordre on a fait ça, les ligatures, ça, et pourquoi on a pris une telle décision. 'est ce qu'on aurait pu laisser un bout de col ou pas?' Je ne me suis pas demandé sur le coup [le seul objectif] c'était juste d'arrêter de saigner. J'avoue que ce n'était pas tout à fait pédagogique. C'était un peu au delà de ça." - $P4_{Int2}$

Section 8.3

"Oui, parce que c'est comme ça qu'on se corrige quand on fait un geste en césarienne, et que si l'opérateur a aucune remarque, ce que ce n'était pas terrible. Bah, déjà, ça permet de se corriger. Ensuite, si je vais voir dans la vidéo et que je vois. 'Ben oui, effectivement, ils font plutôt comme ça', la fois d'après [comme aide], je vais me concentrer à faire plutôt comme ça." - $P6_{Int2}$

"Plus j'avancerai et plus je m'intéresserai à différentes choses sur cette vidéo. Je trouve que justement elle est faite pour la revoir plusieurs fois au fur et à mesure de notre avancée, parce que là pour l'instant je la prenait un peu en mode informatif, mais après une fois que j'en aurais vu plusieurs, ce sera 'pourquoi est-ce qu'on met les choses [pinces] comme ça', 'comment on fait'. Je trouve qu'on a une lecture différente de la vidéo au fur et à mesure de l'avancée de notre niveau." - $P2_{Int2}$

Section 9.1

"Après, je pense que les structures, ça reste les mêmes [entre hystérectomie cœlioscopique ou ouverte]— ce n'est pas le même angle d'abord, ce n'est pas la même vision exactement, mais en soi, ça reste les mêmes étapes dans plus ou moins le même ordre mais avec les mêmes structures. Donc, je pense que oui, ça m'aidera quand même à mieux visualiser les structures anatomiques." - $P5_{Int2}$

"Oui, là où ça m'a été un peu utile, et, j'ai trouvé ça intéressant, c'était la partie décollement vésical, puisqu'on en fait un peu en césarienne. Et j'ai trouvé ça marrant d'avoir l'apport un peu plus chirurgical, parce qu'en césarienne c'est un peu 'euh la vessie qui nous gêne, allez on débarrasse'. Mais oui, c'était un peu plus détaillé [...] ça a été intéressant." - $P4_{Int2}$

"Depuis que j'ai vu la vidéo, je n'ai pas fait d'hystérectomie. Mais par contre, j'ai fait des césariennes, et comme dans la vidéo ça détaille bien le pfannenstiel, je m'en suis servi en césarienne. Ça m'a aidé en césarienne." - $P6_{Int2}$

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