Understanding Undesired Procedural Behavior in Surgical Training: the Instructor Perspective

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Abstract. In recent years, a new approach to incorporate the process perspective in the surgical procedural training through Process Mining has been proposed. In this approach, training executions are recorded, to later generate end-to-end process models for the students, describing their execution. Although those end-to-end models are useful for the students, they do not fully capture the needs of the instructors of the training programs. This article proposes a taxonomy of activities for surgical process models, analyzes the specific questions instructors have about the student execution and their undesired procedural behavior, and proposes the *Procedural Behavior Instrument*, an instrument to answer them in an easy-to-interpret way. A real case was used to test the approach, and a preliminary validity was developed by a medical expert.

Keywords: undesired procedural behavior, process perspective, healthcare, medical training, surgical procedures, surgical process models.

1 Introduction

In medical education, a common task is to teach surgical procedures. To analyze how students perform it, videos of their executions are recorded. Then, the instructor watches them to evaluate their students and provide feedback to them.

Recently, Process Mining has been used to incorporate the process perspective into the medical training of surgical procedures [9]. Process Mining is a novel technique that allows to discover the different variants in which a procedure is executed, compare the executions versus a reference model of the procedure, and also identify opportunities to redesign the procedure [1]. In order to do that, the aforementioned videos are tagged by a human observer, who then uses a software to transform the tagged videos into an event log [9]. Process mining allows a procedural analysis on the execution performed by each student, so as to provide feedback about their performance. The end-to-end process models allow to provide feedback to them so as they focus their efforts to avoid the same mistakes in the future [9]. Although these end-to-end models are useful for the students, they do not fully capture the needs of the instructors of the training programs, because they do not provide global information about the whole class. It also does not allow instructors to observe stages of the procedure that need more supervision during training, or to easily visualize undesired execution patterns.

To address this problem, in this article we propose a two-part approach. The first part is a taxonomy of activities that allows categorizing the activities of a process model of the procedure considering its semantics, and a set of relevant procedural questions based on such taxonomy. The second part is the design of the *Procedural Behavior Instrument*, an instrument that shows undesired patterns in a twofold way, i.e., for a specific student and for the whole class.

The structure of the article is as follows. First, the real case used as a running example to show the proposed approach is explained. Then, the taxonomy of activities for surgical procedures is proposed. Afterward, the questions of interest for instructors are presented. Later, components of the *Procedural Behavior Instrument* are shown, how to compute them and how they are represented. Then, results obtained from the preliminary validation carried out by an instructor (medical expert) are presented. Finally, the main conclusions of this article are highlighted.

2 The Running Case: Central Venous Catheter

To illustrate the proposed approach, the installation of a Central Venous Catheter (CVC), hereinafter the *CVC case*, is used. This procedure has an initial stage that is the preparation of implements and the patient. Then, a trocar (instrument used to access or drain body fluids) is installed in the vein with help of ultrasound. Next, a guidewire is passed through the trocar, and after checking that it was installed correctly, the trocar is removed. After, the catheter is installed with help of the guidewire. Finally, the guidewire is removed and the catheter is installed [10].

A BPMN model representing the procedure was developed establishing the consensus of physicians using the Delphi method [5]. The model can be seen in the following section (Figure 1). Twenty medical residents of the specialty of anesthesiology at the Pontificia Universidad Católica de Chile participated in a training program in which process-oriented feedback was provided to the students in order to enhance their learning [2, 9].

3 Surgical Procedure Activities and Undesired Behavior

The first part of the approach proposes a taxonomy of surgical procedure activities, because it has been seen that enriching the formalization of surgical process models benefit the teaching of these procedures [8]. Then, based on this taxonomy, the approach defines three questions of interest for instructors related to procedural undesired behavior.

3.1 Surgical Procedure Activities

If we talk about processes in general and abstractly, a process is composed of a series of steps (activities) that must be performed in a certain order, e.g., first execute a, then b or c, and finally d. This definition also applies to surgical procedures, but with one difference: surgical procedures are accompanied by a semantic and a domain where they are applied, which allows to establish differentiating characteristics among the activities. For example, in the *CVC case*, to puncture the patient to place the trocar is not the same as to check that the trocar is correctly placed. The first is a step with an active role in the process and has effects on the patient's body, while the second has a controlling role on the correct performance of the first step.

Our approach proposes the distinction of activities in four groups:

Action *Activities that progress the status of the surgical procedure.*
These activities are associated with invasive activities for the patient or that may cause some level of pain, such as punctures, inserting or installing different elements, among others. In the *CVC case*, "Puncture", "Guidewire install" and "Advance catheter" are examples of action activities.

Identification *Activities that identify an element before an action activity.*
These activities correspond to the detection of some element that will be intervened in an action activity, such as the identification of a vein or some organ. In the *CVC case*, "Anatomic identification", "Doppler identification" and "Compression identification" are used to identify the vein.

Control *Activities that control the progress after performing an action activity.*
Surgical procedures can include the realization of a control activity after an action activity (or a sequence of action activities) to verify that it was executed correctly (for example, that something has been installed correctly). In the *CVC case*, "Blood return" controls that it has been punctured the vein in the right place.

Preparation *Activities that define the steps to prepare the execution of the surgical procedure.*
These activities are carried out before the execution. They are any activity prior to the execution of the procedure, such as preparing the implements,

tools, supplies and the patient for the procedure. For example, in the *CVC case*, “Hand washing”, “Ultrasound configuration” and “Put sterile gel” are examples of preparation activities.

Our approach defines the four groups of activities as disjoint, i.e., an activity cannot belong to two groups at once. This is sufficient for most processes, but other more complex processes may require expert domain knowledge. In turn, an activity difficult to classify can be transformed into two or more new activities, which can be categorized in one of the four proposed groups.

Figure 1 shows the application of this approach to the *CVC case*. The BPMN model [5] has been enriched according to the defined taxonomy.

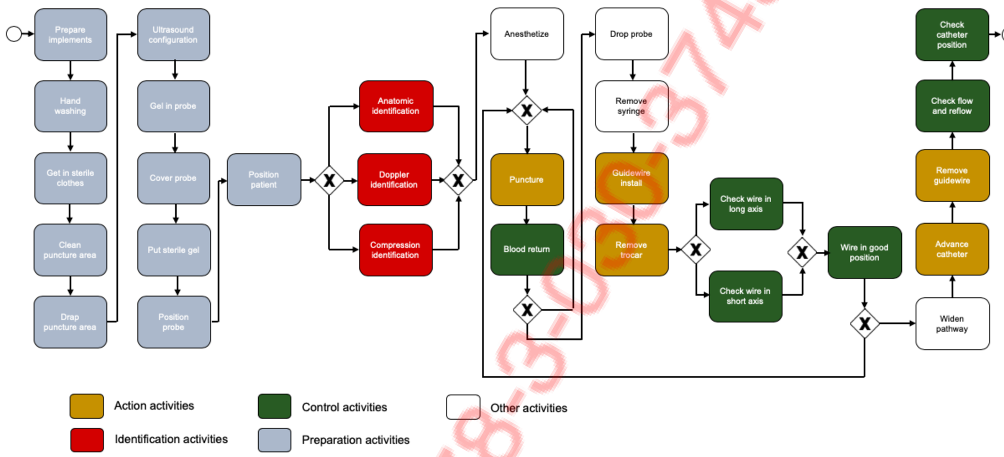

Fig. 1. BPMN model with the taxonomy of activities.

3.2 Undesired Behavior

We define undesired behavior as any pattern that indicates little fluidity throughout the execution of the procedure, e.g., perform again an activity that is specific to the beginning of the procedure, repeat a part of the process, or do not check an action activity. Detection of undesired behavior is relevant in the instruction of the procedure, so as to correct errors promptly. Therefore, instructors need to identify them quickly and easily.

Based on expert knowledge in the teaching of surgical procedures, our approach proposes the following three questions of interest to discover undesired behavior [11]:

Q1 *What patterns show an undesired sequence of action activities during the execution of the procedure performed by a student?*
The answer to this question allows to discover in which action activity students usually go backward in the procedure, if they skip any of them, and if they repeat them many times.

Q2 *What patterns show an undesired use of identification and control activities during the execution of the procedure performed by a student?*
This allows the instructor to know if students perform the necessary checks after an action activity, and where in the process they perform control and identification activities. It also allows to know if a student execute the procedure with confidence.

Q3 *What patterns show an undesired use of preparation activities during the execution of the procedure performed by a student?*
Preparation activities are carried out before the procedure begins. Their execution during the procedure is an undesired pattern, since it shows that the student did not plan the procedure in advance.

There are other types of undesired behavior when performing the steps of the procedure, e.g., the amount of anesthesia injected is not correct, or releasing the guidewire while installing. However, they are not related to the execution of the procedure from a process perspective. These behaviors can be analyzed with other instruments, such as checklists or global scales [6, 7].

4 Procedural Behavior Instrument

The second part of the approach considers the design of an instrument that allows answering the three questions of the previous section in an easy and direct way for an instructor, which is not necessarily expert in process analysis. The instrument, called *Procedural Behavior Instrument*, is composed of 4 components: rework, checking, verification and preparation. Each component is twofold, i.e., it provides a view at the student level and a view at the level of the whole class. The rework and preparation components have been designed to answer questions Q1 and Q3, respectively, while Q2 is answered with the checking and verification components.

This article defines, for each component, how to compute and represent the different procedural behaviors using the taxonomy of activities defined in the previous section. Calculation and representation is done for a particular student and for the whole class, so the instructor can observe the undesired patterns at both levels. To understand the components, lets define $\sigma_k = \langle e_1, ..., e_m \rangle$ as the sequence of steps (i.e., activities) executed by the student k, and e_i as the event performed in the position i of the sequence σ_k.

4.1 Rework Component

This component allows the instructor to know in which activity of the procedure students go backward, if they skip any activity, and if they repeat some part of the process many times. It shows the number of times a certain pair of action activities is executed.

For this component, the events of σ_k that are action activities are used, because they are the ones that determine the progress of the procedure execution.

In the case of student k, rework is the number of times each pair of action activities are followed directly in σ_k, i.e. $\langle e_i, e_{i+1} \rangle$. Figure 2 shows that student k executed twice the pair "Puncture" $\rightarrow$ " Guidewire install", and once the pair "Remove guidewire" $\rightarrow$ "Puncture". This means that student k executed the action activities until the end, but then went backward and executed all the action activities again.

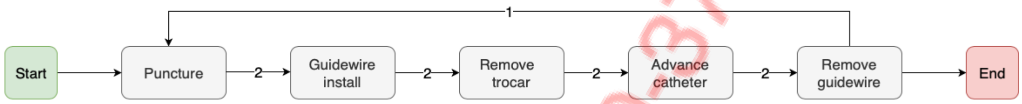

Fig. 2. Rework component for student k.

For the whole class view, the number of students performing each pair of action activities at least once is calculated. Figure 3 shows that three students consecutively repeat "Puncture", one student did not perform "Advance catheter", and three students after performing "Remove Guidewire" returned to "Puncture", so they probably had to execute all action activities again.

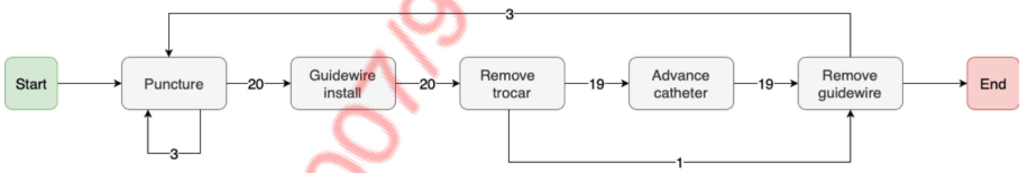

Fig. 3. Rework component for the whole class.

4.2 Checking Component

This component shows the number of identification and control activities performed during the procedure. This allows the instructor to determine if the identifications and controls established by the model are being performed.

For this component, σ_k events that are action, identification and preparation activities are used.

For student k, the number of identification and control activities that were performed before and after each action activity are calculated. Figure 4 shows student k performed three identification activities before “Puncture” and two control activities after “Puncture”. The number to the left and to the right of each action activity indicate the number of identification and control activities that were performed, respectively. If there is no number means that, according to the model, it is not necessary to carry out those activities.

Fig. 4. Checking component for student k.

For the whole class view, the number of students who performed identification and control activities before and after each action activity at least once are calculated. Figure 5 shows that the twenty students of the class performed the identification of the vein before “Puncture”, and that only eighteen of them controlled that the guidewire was installed correctly. The number to the left and to the right of each action activity indicate the number of students who performed the activities. If there is no number means that, according to the model, these activities are not required.

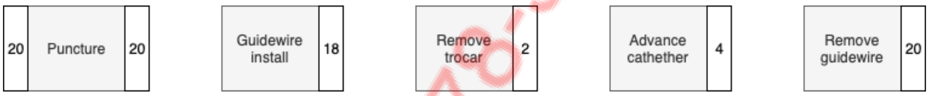

Fig. 5. Checking component for the whole class.

4.3 Verification Component

This component shows whether the identification and control activities are being performed each time an action activity is performed. Compared to the checking component, it considers not how many identification/control activities are performed but whether they are performed or not each time the action activity is performed.

For the calculation of this component, events of σ_k that are action, identification and control activities are used.

To determine if student k performed the identification activities required to perform an action activity, the following should be considered:

- If it is one identification activity, it must be performed at least once just before the action activity.
- If it is more than one identification activity, they must be performed in the order defined in the model.

To determine if the student k controlled that he/she performed the control activities to verify if the action activity was executed correctly, the following should be considered. Let's suppose we have a set of control activities to control the correct execution of an specific action activity:

- If the set has only one control activity, it must be executed at least once just after the action activity.
- If there are two or more control activities in the set:
  - Control activities should be executed in the order defined by the process model of the procedure, just after the action activity.
  - If the student executed at least one of the control activities of the set just after the action activity, and then execute a prior activity (according to the order defined by the process model of the procedure), we consider that student controlled the action activity. This is because if the student performed at least one of the control activities of the set and then executed a prior activity, we assume the performed control activity was enough for the student to realize that he/she was not performing the procedure correctly.

In the representation for student k, it is marked with 'X' if the student did not perform either an identification or a control activity each time the action activity was executed, and with '✓' if it was performed. At the center is the action activity; on the left, the percentage of times the student correctly performed identification activities; and on the right, the percentage of times the student correctly controlled the right execution of the action activity. If there is nothing, it means that, according to the model, it is not necessary to perform either the identification or the control activities.

Figure 6 shows the verification component for the student k. The student performed "Puncture" twice, the first time the identification was performed while in the second time it was not. It also shows that the two times "Puncture" was performed, the control activities were performed correctly. In the case of "Advance catheter", the single time the student placed the catheter, he/she did not control whether it was installed correctly.

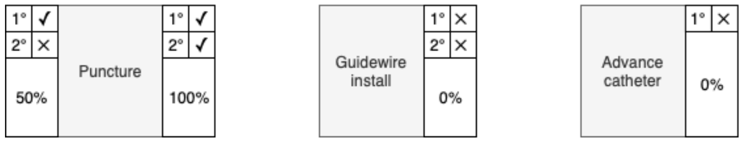

Fig. 6. Verification component for student k.

In the representation for the whole class, at the center the action activity is shown; on the left, the percentage of cases in which the identification was performed every time the action activity was executed; and on the right, the percentage of cases in which the students controlled that they had performed correctly the action activity. If there is nothing, it means that, according to the model, it is not necessary to perform either the identification or the control activities.

Figure 7 shows the verification component for the whole class. 90% of the students performed the identification of the vein before puncturing, and 80% of the students controlled that they had punctured correctly.

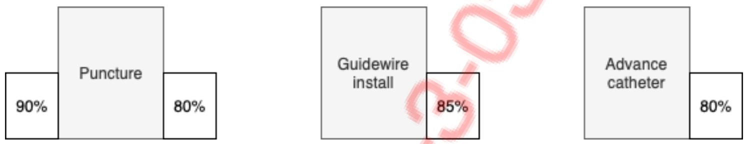

Fig. 7. Verification component for the whole class.

4.4 Preparation Component

This component allows the instructor to know if students successfully completed the preparation of the procedure. An unsuccessful preparation would be detected if there are preparation activities performed during the execution of the procedure.

For this component, the σ_k events that are action and preparation activities are used.

For student k, the number of preparation activities performed before an action activity (excluding the first action activity, since prior to it all the preparation activities should have been completed) is calculated. Figure 8 shows that student k executed the procedure in an undesired way, since a preparation activity was performed before "Guidewire install"; and another one, before "Remove trocar".

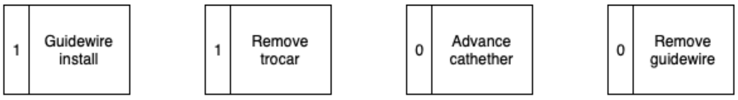

Fig. 8. Preparation component for student k.

For the whole class view, the number of students performing preparation activities at least once before each action activity (excluding the first one) is calculated. Figure 9 shows an undesired pattern in the executions of the training program, since four students performed preparation activities before "Guidewire install" and three students before "Remove trocar".

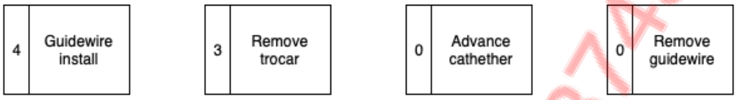

Fig. 9. Preparation component for the whole class.

5 Preliminary Evaluation

The simplest way to validate an artifact is by expert opinion, in order to evaluate if the artifact would perform correctly in the contexts imagined by the expert [12]. With this in mind, a preliminary assessment of the validity of the proposed approach was performed by one of the instructors (a medical expert) of the training program of the *CVC case*.

The instructor considered the proposed taxonomy of activities to be significant to understand the procedure, as well as to analyze it and refine it. In addition, the instructor considered that the visualization of the BPMN model (see Figure 1) allows to comprehend the *Procedural Behavior Instrument* more easily. The instructor highlighted the use of different colors for each type of activity in the BPMN model.

The *Procedural Behavior Instrument* was preliminarily validated by the instructor through the adaptation of the questionnaire PUEU (Perceived Usefulness and Ease of Use) [3], widely used to evaluate the perception of usefulness and ease of use of IT systems.

Regarding to the perceived usefulness, the overall assessment of the instructor was positive. The instructor emphasized that the *Procedural Behavior Instrument* would allow greater effectiveness in the identification of undesired patterns in the executions carried out by students. Other positive aspects are: the *Procedural Behavior Instrument* allows to identify the undesired patterns more quickly and easily. Regarding the perception of ease of use, the instructor's overall opinion was also positive, highlighting the ease of interacting with the *Procedural Behavior Instrument*. However, the instructor considers that it is not easy to learn to interpret the components; in this sense, a prior introduction would be required before using it.

Additionally, the instructor was asked open questions regarding the *Procedural Behavior Instrument*, considering both positive aspects and aspects to improve.

Among the general positive aspects, the instructor highlighted that the *Procedural Behavior Instrument* allows a panoramic view of the execution of the procedure, allows to compare a particular student versus the whole class, and the distinction of different kind of activities in the execution of the procedure. Regarding the specific components, the instructor commented that they were all useful, highlighting the possibility of identifying when students go backward in the process (rework in Figure 2), and to identify when checks were done more times than expected (see Figure 6).

Some aspects to improve are design details typical of a prototype version, such as the incorporation of context information (e.g., the number of students in the class, how many students were able to complete the procedure, and providing the model of the process in advance). However, the overall evaluation is positive in terms of its potential to support the instructor's work, and its learning for future executions.

6 Conclusions and Future Work

As [4] mentions, Interactive Pattern Recognition can support physicians in their daily practice. This article shows the use of a process perspective to recognize patterns on students' performance in medical training, and afterwards it analyzes how instructors interact with the patterns discovered.

In this paper, we propose a taxonomy of activities for surgical procedures and the development of the *Procedural Behavior Instrument*, an instrument that allows the instructor of a training program (in a surgical training context) to know what are the undesired patterns performed by their students. The taxonomy contributes to the formalization of surgical process models, helps to establish a hierarchy of activities to evaluate students, and facilitates the analysis of surgical process models. In turn, the *Procedural Behavior Instrument* allows instructors to easily discover undesired patterns in the execution of each student's procedure and in the executions of the whole class. With the *Procedural Behavior Instrument*, the instructor can easily observe patterns related with action activities (Q1) using the rework component, patterns related with identification and control activities (Q2) using the checking and verification component, and finally, patterns related with preparation activities (Q3) using the preparation component.

The approach was applied to a real case, the *CVC case*, and was preliminarily validated by an instructor. A limitation of this approach is that the *Procedural Behavior Instrument* is a prototype, so there are details that need to be tuned. The preliminary validation was very important to know what things to improve of the *Procedural Behavior Instrument*.

In the future, we expect to generate a *Procedural Behavior Dashboard* designed for instructors, which is going to allow them to know the undesired behaviors in a more friendly way. In addition, we plan to test the proposed approach with a larger group of instructors.

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