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Revealing misleading schemes through operator activity analysis: A factory case study

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Abstract

This article presents an activity analysis carried out in an aeronautical factory. The representation of the real process and the operators' representations were identified. The representation of the real process was elaborated using an abstraction hierarchy, as described by the ecological interface design framework. The operators' representations were extracted through interviews and observations and described in terms of schemes. The analysis revealed that operators in the studied factory used misleading schemes (i.e., false representations) to organize their activities, resulting in poor performance. We conclude by offering possible remedies, including training aimed at inhibiting the misleading scheme and a simulation tool to convey a more accurate representation.

KEYWORDS

activity analysis, aeronautical factory, misleading scheme

1 | INTRODUCTION

This article presents theoretical questions raised by a field analysis. The objective of this analysis was to expand on propositions for the development of a tool aimed at assisting operators during the fabrication process. Such a tool (which is not presented here) uses online simulation of the underlying physical process to help operators carry out a particular task. As presented in Section 1.1, the task presents challenging issues in terms of activity analysis in a dynamic environment. More specifically, the industrial process seems to favor misleading schemes, that is, false representations.

The goal of the study was to evaluate the existence and potential effects of a misleading scheme on operators' work. To do so, it was essential to develop a correct description of the task through an abstraction hierarchy (see Section 3). The operators' mental representation of the process was then assessed to identify potential inaccuracies and any consequences for the operators' performance (see Section 4). The practical use case is presented, followed by the theoretical frameworks used for its conceptualization and any associated methods. We conclude with a discussion about the existence of misleading schemes and recommendations for possible remediation (see Section 5).

1.1 | Presentation of the use case

The workshop under consideration belongs to an aeronautical factory. The factory shapes metal frames that are used as the skeletons of airplanes. These long metallic frames are brought to the factory to be bent and trimmed. Metal panels are eventually fixed to these frames; together, they make up an airplane's fuselage. To achieve this goal, the frames must go through many transformations (see Figure 1).

In this study, we focused on an examination of the stretching and bending task. During this task, the operator stretches and bends a straight metallic frame to give it its final curved form (see Figure 1). These frames are U- or T-shaped in their section and can measure up to 10 m long. The stretching task itself is divided into two steps. To transform the frames, the operators must manipulate a stretching machine and several tools. With regard to running the frame-stretching machine, the operators must execute predefined programs. However, they can modify the program by increasing or decreasing the length or angle for stretching. More precisely, they can change the position of the machine's hydraulic arms at the end of the stretching session. The main tools used during the stretching task are the tracks, which are long elastomer pieces that are supposed to maintain the frame's shape during stretching. For each frame reference, only one set of tracks exists; this may represent a problem as frame characteristics can vary, even within a given batch.

After the first stretching step, the characteristics of the frame are modified by a tempering process. During this process, the frame becomes more ductile for a couple of hours; after this time, it becomes tougher. An operator can slow the toughening process by putting the frame in a cold chamber known as the fridge. The frame is then stretched and bent again until the required dimensions are reached. Following this, the frame goes through another furnace, where the maturation phenomenon occurs; it should then be tough enough to play its role as part of an airplane's fuselage. Finally, as the frame's dimensions need to be exact, it is trimmed by an automaton and manually calibrated. The frame goes through the furnace for one last time.

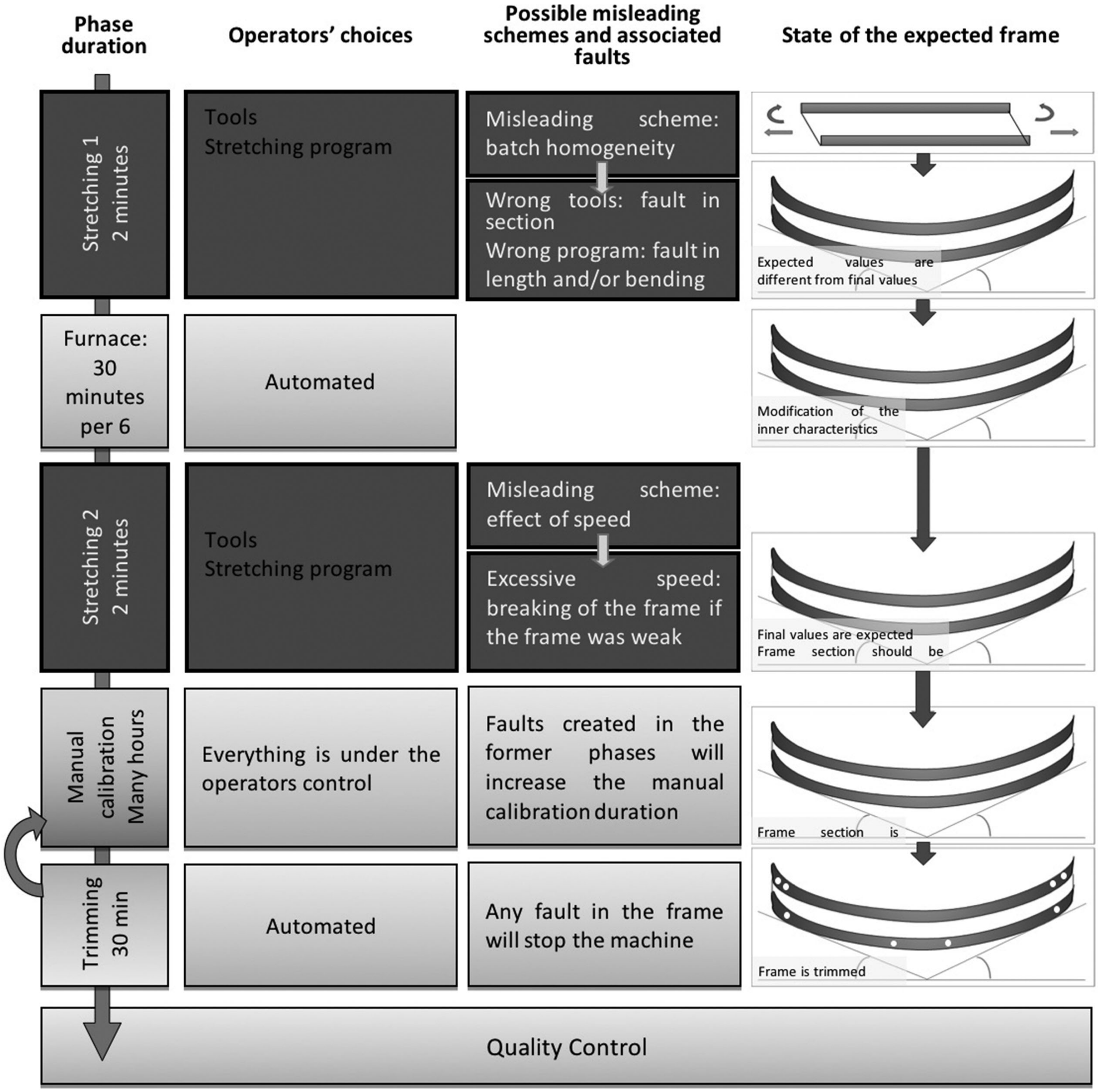

FIGURE 1 Synthetic presentation of the factory. The schema presents the different phases of the process, the decisions made by the operators, the mistakes they can make in the stretching and bending task and the state of the frame after each phase as it should be if the process was perfect

This manual calibration task can last many hours, up to 6 hr per frame; therefore, it is the longest and most expensive task in the whole process. On the other hand, the automated stretching process lasts between just 2 and 6 min per frame and the automated trimming only 30 min for a set of six frames. Furthermore, the calibration task is entirely manual, which means that many operators are required. Most operators consider these calibration tasks to be laborious. Both the factory management and the operators believe that an improvement in the stretching process could reduce the time spent on calibration tasks. Indeed, the stretching and bending machine can often give random results. Thus, we can assume that the machine control task could be improved by providing the operators with an accurate decision-making tool.

This use case is particularly interesting, because unobservable elements influence the results of the process. First, the inner characteristics of the frame impact on the way it reacts to the stretching step: depending on these characteristics, the frame ends up being more or less stretched and curved. The precise values of these inner characteristics are unknown to the operators at the beginning of the process and cannot be measured unless the frame is destroyed. A mean value is given by the displayer for each batch, but this information is not used. As a consequence, every frame of a given reference is stretched using the same program. Moreover, after a thermic treatment that all frames have to sustain, these inner characteristics can change as a function of time. Consequently, an operator is not aware of the exact characteristics of a frame when he begins the stretching process. Finally, the frame's shape may hinder the process, because the tracks used may not be an accurate fit. Therefore, applying a stretching protocol that has the same program and the same tools to a frame with the same reference may result in different final frames. Consequently, the measured values will not be within tolerance.

1.2 | Theoretical frameworks

This case study matches the main characteristics of a dynamic environment (Hoc & Amalberti, 2007), namely, uncertainty, partial control, time dynamics, and multiple treatments.

Classically, in a work context, a dynamic situation refers to complex tasks in which there are changing parameters over time, as well as uncertainties (Hoc & Amalberti, 2007). The operators must then choose their actions according to their goals and their knowledge or representation of the current situation. The operators cannot know everything about the situation nor can they completely master it (Hoc, 2005). As a result, the operators will only have partial control of the situation, with consequences for the cognitive processes involved. The operators deal with temporal dynamics (i.e., system dynamics and the operator's own cognitive system), multiple representations of the situation (i.e., different points of view and possible outcomes), uncertainty, and multiple tasks (sometimes with contradictory goals).

In this particular condition, an individual must have limited knowledge of how to construct a latent representation of the system under control. The scheme framework can be of interest, helping operators to better understand how such latent representations can develop and allowing them to grow in competence. Our use of the term *scheme* is grounded in Piaget's definition, which has been used in ergonomics studies (Béguin & Rabardel, 2000; Rogalski, 2004). Piaget introduced the concept to describe those elements of infant cognition on which development relies; thus, it has a dynamic dimension. Developmental psychologists, such as Vergnaud (1991) and Pascual-Leone (1987), further developed the concept of scheme. According to Vergnaud (1991, 1996, 2009), a scheme is an invariant organization of one's activity in a given class of situations. In other words, it is a representation of the world that enables action. The organization of an activity is the invariant, rather than the activity itself. Organization is made up of five elements:

- Rules for Action (RA): what needs to be done to fulfill a given goal.
- Anticipations (An): the expected results of one's action.
- Inferences (In): calculations that adjust the current action to match the characteristics of a situation. As these calculations are not directly available, the evidence, used as the basis for these calculations, is used to describe a scheme.
- Operative Invariants (OI): information, knowledge, or beliefs that may be correct or incorrect. One considers it as true or pertinent to fulfill an action to achieve a desired result.
- Artifacts (Ar): tools used to help execute an action.

The scheme framework has already been used to analyze activity in a dynamic situation (Rogalski, 2004). For instance, Pastré and colleagues used the scheme framework in their study of operators of an injection press machine (Pastré et al., 2009; Pastré, Mayen, & Vergnaud, 2006). They used interviews to show that the operators in this case had developed different strategies to perform a particular task. Their work aimed to study and develop competences and was embedded in the didactic literature.

Even when there is an operating scheme for an activity, it does not mean that this scheme will always be accurate. Pascual-Leone (1987) proposed the notion of a misleading scheme to define these nonaccurate schemes. In fact, one can develop an efficient scheme in one particular activity but would not lead to an expected result if confronted with a more general or more specific situation (Pascual-Leone & Johnson, 2010). Regarding this case study, a lack of information can be seen to place the operator in a situation of cognitive underspecification (Reason, 1990). As such, an individual lacks the necessary knowledge and/or information to solve a problem. For instance, if an operator needs to find out how to program a machine that transforms a metal piece but has no information about the kind of alloy it is made of, the operator may not be able to do it. Cognitive underspecification usually leads to errors. Through repetition, and with a lack of sufficient feedback, a simple error can be turned into the inaccurate organization of an activity, that is, a misleading scheme. Moreover, it is important to distinguish between a misleading scheme and a heuristic, because they are closely related concepts. A heuristic is a problem-solving technique used by experts, which relies on selected and partial information (Gigerenzer & Gaissmaier, 2011). It can thus be considered a scheme as it is a way of organizing activity. However, if heuristics are schemes, all schemes are not heuristic. Moreover, even though the use of heuristics can be considered biased, an expert operator should be able to determine whether a heuristic is efficient (Charness & Tuffiash, 2008; Dreyfus & Dreyfus, 1980; Hoc, 2005). A misleading scheme can appear during training and be used by novice operators who are not able to determine whether or why the misleading scheme is inaccurate.

1.3 | hypotheses

With regard to this case study, a lack of information and feedback, and a lack of opportunities for the operators to make corrections, may contribute to the development of such a misleading scheme. In particular, in this study, misleading schemes may exist. These misleading schemes may be used by novice operators at the aeronautical factory.

Three main hypotheses are explored here. The first one is that the novice operator will have misleading schemes among his representations. The second one is that the expert operator will not have such misleading schemes. Finally, the third hypothesis states that, when performing an activity, a novice operator will use some of these misleading schemes.

2 | METHOD

To determine whether misleading schemes exist among the factory's operators, a three-phase protocol was used. The first phase was aimed at describing the process and any underlying physical laws in existence. This description is the reference against which the operators' latent representations were compared, that is, the correct representation. To define this correct representation, it was important to first analyze the work domain. The second phase was aimed at collecting the operators' schemes through interviews. Finally, the third phase consisted in observing the operators to determine whether they used misleading schemes during their activities. The data collected during this observation were analyzed through statistical generalized linear models.

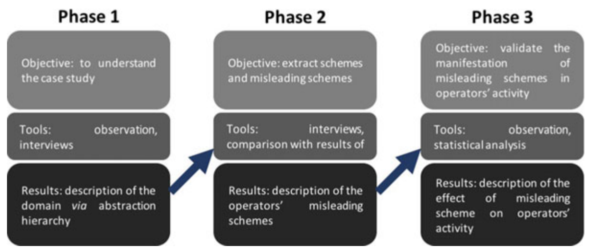

FIGURE 2 The different phases of the method used throughout the study. The observation and information gathered during phase 1 helped in identifying misleading schemes in phase 2. The data gathered in phase 3 were analysed according to results of phase 2, i.e. misleading schemes

For a better understanding, each phase of the protocol is described in detail before the presentation of the results. A synthesis of the method and of the different study phases is presented in Figure 2.

3 | UNDERSTANDING THE CASE STUDY

3.1 | Method

The first phase of the study aimed to gain a better understanding of the global process involved in the use case: frame stretching and bending. Before this observation phase, we had no knowledge of the production process, hence the importance of this phase.

First, a preliminary observation was conducted to record the various steps involved in the transformation process within the factory. These observations took place over 4 days. The first day was dedicated to a global observation of the factory. During the three remaining days, two pairs of operators, who were working on the semiautomated task of stretching and bending, were observed. Finally, we examined documentation about the process given to us by the factory's employees: task description, machine handbook, and frame description. In parallel, two researchers from the field of physics were interviewed to better understand the underlying physical rules that influence the process. These two physicists, both specialists in aluminium alloy bending and stretching, worked at École Centrale de Nantes as a doctoral student and a professor. The professor is considered an expert on this topic as he has been working for 20 years on metal and composite alloy. The doctoral student was working under the professor's supervision on the simulation of the alloy reaction during stretching. They were able to gain access to the factory during the study and were also engaged in the simulation of the stretching and bending task. By gathering these elements, we were able to gain a wider understanding of the general process.

The abstraction hierarchy seemed the most relevant for structuring the information collected during this phase. This framework is particularly useful for the analysis of dynamic situations. The abstraction hierarchy tool was first described as part of cognitive work analysis (Vicente, 1999). However, many different and more recent descriptions of this approach exist (Flach, 2015; Naikar, Moylan, & Pearce, 2006). In this study, however, the work domain has been restricted to a single task, with the final goal to make recommendations for the interface of a simulation tool. Thus, we used the definition and methods proposed by Bennett and Flach (2011) within the ecological interface design framework. Their description of abstraction hierarchy is efficient enough for a work system in which the main constraints are imposed by physical laws (Christoffersen, Hunter, & Vicente, 1996), as is the case in the task studied here.

This first phase allowed us to elaborate an abstraction hierarchy. Later, this abstraction hierarchy was presented to several factory employees and revised according to their feedback. The veion presented in Figure 3 is the revised version. This hierarchy was used as a reference for the analysis of the factory operators' representations and schemes. Thus, the abstraction hierarchy was instrumental for the activity analysis and the identification of misleading schemes. Indeed, operator representations were compared with the abstraction hierarchy and discrepancies revealed misleading schemes.

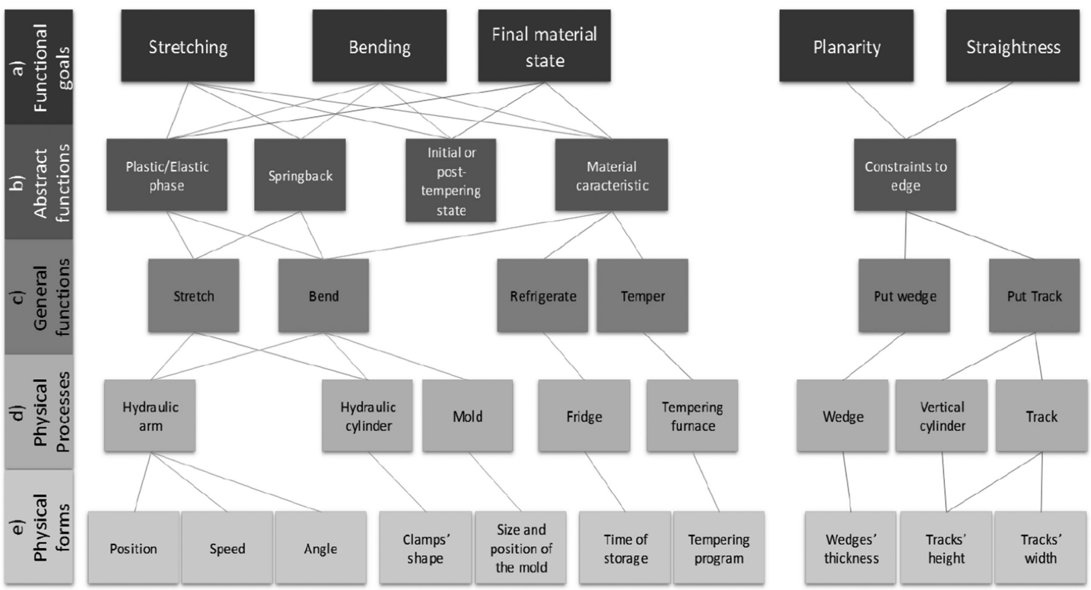

FIGURE 3 Mean-End hierarchy for the stretching and bending task

3.2 | Stretching and bending task

In this use case, the stretching and bending task is carried out twice: first, when the frame has just arrived in the factory and a second time after tempering. There are few differences between the two tasks: the main change, however, is the frames' shape, which is already curved during the second stretching.

In this task, two operators work together. A support operator only helps with handling the frames (which are up to 10 m in length); it is the pilot's job to control the process and the machine. The control panel indicates the position of the two hydraulic arms of the machine and the state of the clamps (open or closed). The two operators check the frame tracking sheet to verify the references, the proper stretching program, and that the correct clamps and tools are in place.

The stretching process then begins. The operators first put the frame in the clamps, which are attached to the machine. They then fit the tracks, which are made up of long elastomer pieces designed to maintain the frame's shape during stretching. Afterward, the pilot uses the control panel to activate each step of the program. He also controls the speed of the machine during the process. Finally, after the first stretching step, the operators put the frame in storage or to temper.

According to the job description, after the first stretching, the operators need to check planarity, straightness and length of the first frame in each production order. After the second stretching, they also put this frame on the calibration table to check the angle of bend. Eventually, according to the job description, they keep a constant speed for stretching; this speed may vary in accordance with the initial state of the frame. This means that the pilot operator has to adapt the speed at the beginning of, but not during, the process. The operator can also modify the program from the panel control, although this is forbidden, because the position of the hydraulic arms should not be modified.

3.3 | Abstraction hierarchy

3.3.1 | Functional goals

The main objective of the operators engaged in the stretching and bending task is to achieve the correct dimensions, planarity, and straightness: in other words, the frame must be the correct length and angle, its section must remain flat, and the arms of the U or T must be perpendicular. After a meeting at the factory to present the first version of the abstraction hierarchy, the head of research and technology added to this list the material's final state, as tested by the quality service. These elements represent the functional goals of the abstraction hierarchy (see Figure 3a).

3.3.2 | Abstract functions

According to the two physicists, three elements are particularly important in the stretching and bending process.

The first one is the plastic limit, which determines the minimum strength required to bring the frame to a plastic state. In our case study, this factor is estimated using tests made by the frame's supplier. However, these tests are an expensive and complicated way of acquiring such information, because they need to be carried out on each frame. Moreover, the program only considers the ideal values for a given reference, rather than those that match a particular batch or frame. The second element is the material characteristic, known as Young's modulus. This modulus, which relates to the alloy used, determines how quickly the material returns to its initial position. This return phenomenon, termed the *spring back*, constitutes the third characteristic of the process; it depends on a combination of both the elastic limit and Young's modulus.

In the real process, two more elements have to be considered: the initial or posttempering state of the material and the edge constraints. The material state consists of the inside constraints of the frame; however, it can also include invisible faults. These faults are impossible to predict and can change for each frame. Moreover, after tempering, they change in an unpredictable way, as do the other characteristics presented. The edge constraints are affected by the size of the tools. Furthermore, the track can be too small or too wide, thus impairing the process. Although these edge constraints can be controlled by measuring before one of the stretching steps, this is currently not the case.

We consider that these five elements form the second level of an abstraction hierarchy (see Figure 3b).

3.3.3 | General functions

Thus, the physical laws described in the Section 3.3.2 represent the abstract functions level (see Figure 3b). These laws actually determine the results of the stretching process. To reach the plastic phase and to anticipate the spring back, the operator has to stretch and bend the frame. The operator can also send it to be tempered or refrigerated. Finally, to avoid section deformation, the operator has to fit a wedge and tracks. This corresponds to the general functions level (Figure 3c).

3.3.4 | Physical processes and forms

We can now consider the physical processes (Figure 3d) and physical forms (Figure 3e). The hydraulic arms of the machine facilitate the stretching and bending process. The operator can change the position of these arms and the speed of movement. The speed should not impair the results of the process, except where there is an internal defect. If this is the case, it may bring about the violent breaking of the frame. Hydraulic cylinders hold the frame in place; the operator can change the shape of the clamp on these cylinders. To obtain the exact desired shape, the frame is bent around a mold, the size and position of which can be changed. Finally, to keep the material characteristics after tempering, the operator can refrigerate the frame. The operator decides on the waiting time after tempering.

With regard to the edge constraints, the operator has to insert a wedge and tracks. The size of these two tools is fixed, although the operator can take another reference to attempt to improve the process. When the frames are measured, each has a different dimension.

4 | ACTIVITY ANALYSIS

4.1 | Extracting schemes

4.1.1 | Method

The second phase of the study began 2 weeks after the first observations were made. In this phase, we aimed to identify the explicit representations of the operators, that is, representation of the task characteristics that they were able to describe (Hoc & Amalberti, 2007). The operators were interviewed using a methodology developed to extract schemes, namely, semidirective interviews related to the task (Maurel, 2009; Vermersch, 1990, 1994). The operators were asked what they do and why, whether they always proceed in the same way, and what results they expect. If the operators had difficulty remembering their activity, a reference to the observed behaviors was made. These questions covered the different elements of the schemes: rules for action, operative invariants, inferences, and anticipation. For instance, the first question was, “How do you proceed when you work on this machine?” Most of the time, this question made the operator sequentially describe the tasks. Then a more specific question was asked, “I saw you doing [an action]. What was your objective then?”

Five operators were interviewed. The operators work by pairs on this machine: a pilot who controls the machine and a support for handling operations. Piloting the machine requires specific skill. Thus, the pilot operators hardly ever change. On the contrary, handling operations, which require less specific skills, may be carried out by changing support operators. The operators interviewed in the study were the two pairs of workers observed previously and an additional support operator. They were the only operators in the factory who used this particular machine daily. The first pair were experienced operators who worked on the machine almost every day. The other operators were novices who had been working on the machine for just 2 weeks. We present the data gathered from the pilots’ interviews only, because the support operators claimed they did not know how to control the machine and thus referred mostly to handling operations.

4.1.2 | Schemes

The operators received the same initial training and had the same amount of experience as the coppersmiths (i.e., more than 16 years); however, when it came to piloting the stretching machine, their degrees of experience differed. On the day of the interview, the novice had only worked for 2 weeks on the machine, while the expert had been working on it for 10 years. He had also been involved in the initial programming of the machine when it was installed in the workshop. This initial setup was mostly performed by a process of trial and error.

We present the results obtained from the interviews with two pilots (an expert pilot and a novice). We have classified the interviews according to the scheme framework (Vergnaud, 1983, 2009): operative invariants, rules for action, inferences, and anticipations. Most of the schemes identified during the interviews referred to the standard procedure and appeared to be accurate. These schemes were shared by both the novice and the expert.

TABLE 1 Presentation of the elements of the schemes concerning speed and batch homogeneity

		Novice operator	Expert operator
Speed scheme	**IO**	Speed has an effect on results	Speed has no effect
	RA	I modify the process's speed	
	In	Frame state and faults	
	An	Improve, but not for sure	
Batch homogeneity scheme	**IO**	Each frame is different/frame from same batch are similar	Each frame is different/frame from same batch are similar
	An		I modify program or tools
	In		According to the precedent frame results
	RA	None (forbidden, lack skills)	Improve the results

In addition, two misleading schemes were identified during the interviews. The first one was related to the consequence of speed, the second one to the homogeneity of frames within batches. These schemes are detailed in the subsequent paragraph and Table 1.

The misleading scheme, which was identified in the novice operator's interview, related to speed. Speed was seen to be important, especially after tempering. He also stated that, if the frame has too many faults, he tries to change the speed to improve the results. The speed of the machine appears at the lower level of the abstraction hierarchy (physical form): thus, it is an element the operator can change and it affects the hydraulic arm of the machine. However, according to the physicist, the process can still be considered static. As a consequence, speed should not impair or improve the process, even during the second step. Nonetheless, excessive speed may reveal an already altered frame by breaking it. The expert operator did state, however, that, when the programs were first set up, they tried and failed to modulate the speed in order to limit faults in frame. Thus, as far as he was concerned, speed had no effect on the results of the stretching process.

Both operators referred to the misleading scheme with regard to batch homogeneity. They both claimed that they stretched the first frame, checked the results, and then modified their action for the following frame. Thus, they considered that all the frames in the same batch should have the same characteristics. Paradoxically, they both stated that each frame was different. The characteristics of the frame refer to two elements: i) their inner characteristics and ii) their dimension. The inner material characteristics appear at the second level of the abstraction hierarchy (abstract function; see Figure 3). They have a direct effect on the desired results and should condition the stretching and bending program. The frame dimensions correspond to the constraints to edge, also on the abstract function of the abstraction hierarchy (see Figure 3). They have a direct effect on planarity and straightness, and they condition which tools should be used. According to the physicists, however, each frame should be treated separately.

In parallel, a measurement project, which was led by apprentice engineers in the factory, indicated variations in the geometry of frames, even when they came from within the same batch. Finally, the operators did not seem to take measurements before stretching in order to validate or invalidate the batch homogeneity scheme. These elements led to the conclusion that batch homogeneity was indeed a misleading scheme.

Moreover, even though both operators referred to a misleading scheme related to homogeneity, they did not elaborate on it to the same extent. Indeed, the novice operator did not seem to be able to use it, in contrast with the expert operator. For example, the novice operator said that he did not consider any possible action to improve the process as a function of observing the preceding frame: he simply did not know how to do this. On the contrary, the expert operator had fully developed this scheme and made it effective. He had access to not only the operative invariants and anticipations but also the inferences and rules for action. In other words, he was able to use this scheme during his activity.

Indications of the differences between expert and novice operators were expected to appear through the observations made during the third phase of the study. This third phase should also illustrate the influence of the representation extracted for the actual activity: whether or not the operators used the misleading schemes during their activity.

5 | BEHAVIORAL EVIDENCE

5.1 | Method

The third phase of this study involved the observation of the operators over the course of a week using a detailed grid that categorized all observed behaviors. The aim of this third phase was to gather behavioral manifestations of the different schemes extracted during the second phase.

During this period, the novice and expert pairs interviewed during the second phase were observed. On the final day, another operator was observed. He was considered to be a “mid-expert” because, although he was present when the machine programs were first installed, he had not worked on the bending and stretching task since then. This operator was added to the study, because he was the only operator available on the day of observation who knew the machine. The support operator for the novice pair had also changed; he was now an apprentice. Finally, when the apprentice was taught to control the machine during the second part of the afternoon, his activity was recorded under the “student” label: this operator was also added to the study.

The data were recorded using a touch pad and ACTOGRAM software. A detailed observation grid was produced using notes gathered during the first phase of the study and imported into the software. The grid was made up of the operator's behaviors. Some elements consisted in elementary actions in the task execution; for instance, the launching programs or tool insertion. These elements could not be carried out simultaneously. On the contrary, other recorded elements could be carried out in parallel with task execution, such as gazing at the task, looking away from the task, and chatting with other operators. The extracted data formed a list of 54 actions, each with a start time and duration. The different characteristics of the situation were manually added to this list: the operator's experience, the frame rank and reference, and the session number and time. Only the actions related to the theoretical frameworks and the results of the interviews were analyzed, namely, actions related to the two misleading schemes identified (use of the speed button, measurement, change in the program) and to attention allocation. Differences between operators were expected because they manifested different schemes.

Fifty-four different actions were carried out during the week. The appearance of each observed action per participant, per session, and within a fixed 120-s time slot was counted. A time slot of 120 s was defined because this is approximately a third of the time needed to stretch a frame (mean time of 362 s). Therefore, the week of observation was divided in 193 time slots, which correspond to 193 statistical units. Each action made within a time slot was counted for each participant: the expert (e), the novice (n), the mid-expert (me) and the student (s).

From the hypothesis that the number of the counted actions (denoted Y) follows a Poisson distribution, several generalized linear models (GLMs) were computed. A GLM is a generalization of an ordinary least squares regression. It allowed us to describe a relationship between a measure (Y) and one or more variables (also called predictors and denoted Xi). Here the predictors were the time (in seconds) from the beginning of the activity, the operators, the frame style (i.e., the frame reference), the frame rank, and the stretching step (first vs. second). The models were selected according to the Bayesian index criterion (BIC) using a stepwise procedure. GLMs were used to statistically validate the existence of differences between the operators' behaviors. This statistical tool allowed a link to be established between variables. The procedure allows the testing of many different hypotheses with only one statistical test. Hypotheses state that one of the predictor has an effect on the number of actions. For instance, the number of actions depends on the time, the number of actions depends on the frame type or the operators, or on interaction between these different elements. For each hypothesis, a statistical model, including the dependent variables stated by the model, is made. Among the tested hypotheses, the one relevant to our problematic are the ones that indicate an effect of the operators. As stated in the former paragraph, the best model is identified by BIC. The BIC is a conservative criterion, it is more likely that it chooses the null hypotheses over alternate hypotheses in comparison with other statistical analyses (Wagenmakers, 2007). The total number of observations (193) allows the use of this criterion.

Here, a link between the operator and a specific action was expected, which would indicate that any actions taken differed as a function of the operator. These statistical models are therefore a way of revealing misleading schemes.

After extracting the scheme through the interviews carried out during the second phase, we expected to find some behavioral evidence for its existence. Consequently, this third phase was aimed at evaluating whether the actions of the operators differed according to their mental representations.

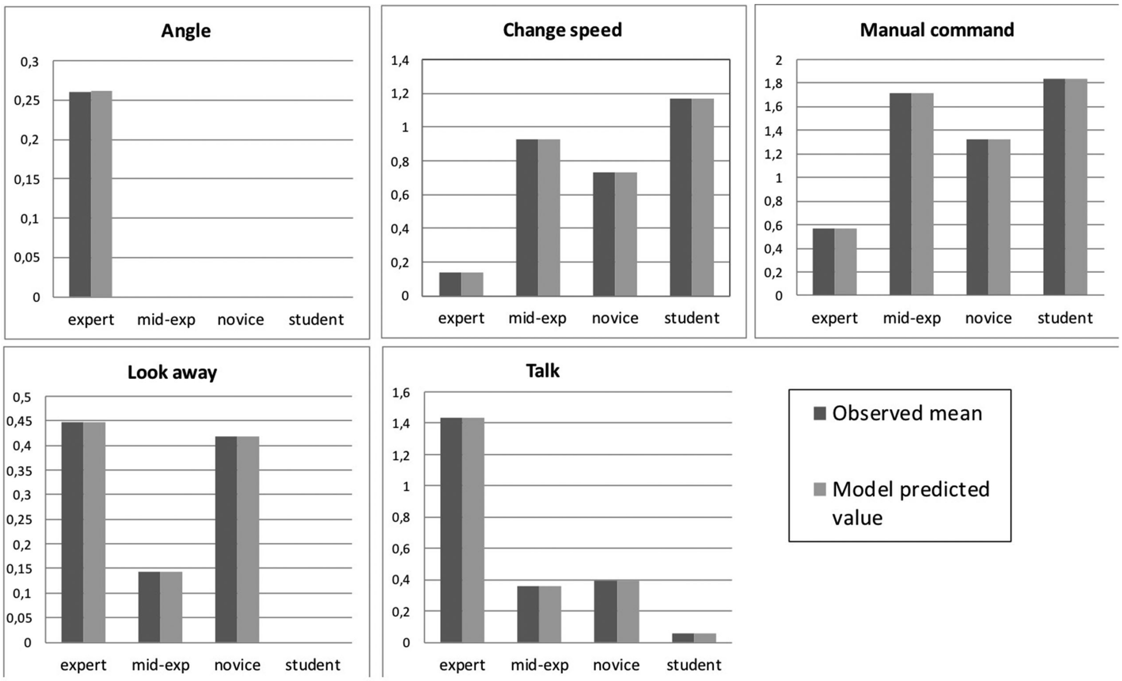

FIGURE 4 Graphical representations of the average number of actions observed within a time slot and model predicted values for ≪ angle ≫, ≪ change speed ≫, ≪ manual command ≫, ≪ look away ≫ and ≪ talk ≫. For ≪ angle ≫ and ≪ manual command ≫, only the second stretching phase was considered

5.2 | Extracted behaviors

Differences between the experts and novices were noticed during the interviews; thus, the objective was to identify whether these differences influenced the operators' behaviors during the task. The operators were observed over the course of 1 week. During this time, the expert operator modified the tools used after noticing a fault on a frame that had already been stretched; however, he did this only once. This behavior can be seen as a direct manifestation of the misleading scheme that relates to batch homogeneity. This behavior only appeared once; thus, it was not significant according to statistical tests. Furthermore, it did not appear significantly more for the expert operator than for the others.

Finally, the results showed that the time taken from the beginning of the activity had no effect. Although computational models were made for each relevant action according to the hypothesis, an operator effect was found for only 5 out of the 54 observed actions: "angle," "change speed," "manual command," "look away," and "talk." This effect means that the operators differed regarding these five actions but not for other actions.

"Angle" was coded each time an operator checked the section's straightness. Measuring the angle represents a control of the activity. Its presence indicates the operator's will to improve the process. This action was observed only during the second stretching for the expert operator. The best model for this action indicates an effect of the stretching step (first vs. second) and of the operator. According to the model, the expert operator is more likely to measure the angle (expected mean for the expert $m_e = 0.26$ action per time slot) than the other operators ($m_{me,n,s} \approx 0$), but only during the second stretching step (Figure 4, "angle").

"Change speed" was coded each time an operator adjusted the speed knob. "Change speed" is an element that indicates the use of the misleading scheme for speed. In the view of the novice operator, it can improve the process. The best model indicated an effect of the operator only. As shown in Figure 4 ("change speed"), the expert uses this button less ($m_e = 0.14$) than the mid-expert, the student, and the novice ($m_{me} = 0.93$; $m_n = 0.73$; $m_s = 1.17$).

"Manual command" was coded each time the operator manually directed the machine's hydraulic arms. This occurred during the second stretching step, with the aim of helping the support operator to fit the curved frame into the clamp and then to center the frame on the machine. This action could indicate the reactive-anticipative dimension of the activity. Actually, more manual commands imply more trials to reach the desired position, whilst fewer manual commands may point to direct success. The best model for this action indicates an effect of both the stretching step and the operator (Figure 4, "manual command"). During the second step, the expert used the manual command less ($m_e = 0.57$) than the other operators ($m_{me} = 1.71$; $m_n = 1.32$; $m_s = 1.83$).

"Look away" was coded each time an operator stopped focusing on the machine or the control panel to look around. The best model specifies an effect of the operator only. Figure 4 ("look away") shows that the expert ($m_e = 0.45$) and the novice ($m_n = 0.42$) looked more away than the other operators ($m_{me} = 0.14$; $m_n \approx 0$).

"Talk" was coded each time an operator talked to the support operator or to anyone else about random nontask relative subjects. The best model for this action considers an effect of the operator only (Figure 4, "talk"). The expert talked more ($m_e = 1.44$) than the others ($m_{me} = 0.36$; $m_n = 0.39$; $m_s = 0.06$). Both "look away" and "talk" are indicators of the operators' distraction. One can assume that less distraction shows that more cognitive resources were allocated to the task and could, therefore, stand for a more symbolic activity.

6 | DISCUSSION

6.1 | Synthesis of the results

The first element revealed by the analysis was "angle." The expert operator was the only one who carried out this action. This action took place for the first three frames during the second stretching step and then for the first frame from a second batch. He used this element as feedback for his activity and to help in decision making. In addition, this measurement was followed on one occasion by a change in the tools used for the stretching of the subsequent frame. These behaviors are in line with the fact that the expert operator considered that all the frames from a batch react in the same way, that is, the expert operator used the misleading scheme relating to batch homogeneity during this activity. Here, the operator acted in a reactive way: he needed to observe a result before acting. However, in this situation, more anticipation may actually be required in order to avoid spoiling a frame or to draw a conclusion based on biased elements. For instance, the operator could take measures or consult the mean value given by the furnisher before the first stretching step and anticipate modifications to the tools or program before stretching. He could then avoid using the first frame of a batch as a test, making sure that the observed values fit the expected values.

With regard to "change speed," the novice operators changed the program's speed more often than the expert. During the preliminary observation, one of the novice operators tried to change the speed in order to improve his results. Consequently, he kept his hand on the speed button all the time so that he could adjust the activity. This could be an indication that the novice operator used the misleading scheme with regard to speed. The expert, on the other hand, only used the speed button to stop the machine or to bring it to maximum speed. According to the abstraction hierarchy, speed has no effect on the results. However, as the novice operator did not check the results, one wonders whether he really used the misleading scheme. Indeed, the fact that he took no measures seems to indicate that he was not completely involved in his activity. This is in line with the fact that he often looked away. With regard to the cognitive control framework (Hoc & Amalberti, 2007), it seems that this operator invested little in the way of cognitive resources to this task. Thus, he probably enjoyed a lower level of satisfaction for his performance of the stretching task. Indeed, he knew that, during the subsequent manual calibration tasks, he was able to correct part of the fault that came from the stretching task. He probably preferred to allocate resources to these manual calibration tasks as he was more familiar with them and had more control over them. However, during the stretching task, the speed button may have been the only element the novice operator had control over. He eventually noticed that speed had no effect but had no other way to control his activity. As a consequence, he seems to have used an altered version of the misleading scheme about speed; this is in contrast with the expert operator who knew that speed had no effect.

The third element identified through the observations was "manual command." This element was not mentioned during the interviews. During the training of the apprentice, the mid-expert gave visual clues to help the student to move the hydraulic arms in the correct way. These elements have probably been integrated by the expert operator, even though he did not explicitly state so. However, this element underlines the mid-expert operator's expertise in using this machine.

Finally, "talk" and "look away" indicated that the expert and novice operators worked with a high level of distraction. The student and the mid-expert seemed more attentive. For the expert operator, this seems in line with his good control of the process and with the greater standardization of the activity. For the novice operator, the standardization of his activity should be put into perspective with his lack of involvement.

The other observed actions did not differ among the operators. Most of them related to a standard activity, such as launching the program, putting the tools into place, and handling the frames. Nonetheless, the gathered elements were sufficient to make recommendations that could be used to improve the process and to design the simulation tool.

Our initial hypotheses were partly validated. The first hypothesis considered that the novice operator would have misleading schemes among his representations. This did indeed occur. However, the second hypothesis stated that the expert operator would not adopt a misleading scheme. This was revealed to be false: the expert operator also manifested a misleading scheme. Finally, the third hypothesis related to the manifestations of the misleading scheme during the execution of a task. This was the case but only on rare occasions.

7 | RECOMMENDATIONS

The first part of this study allowed us to describe the process under observation. It gave a perspective on what the proper representation of the stretching program should cover, particularly with regard to how the frame's inner characteristics could impair the results. When this representation was compared with the representation of the field operators, the existence of two misleading schemes was clearly identified.

7.1 | Avoid the misleading scheme relating to speed

The first misleading scheme identified is related to the speed of the process. The novice operator considered that speed could have a positive or negative effect on the results. However, he was not able to determine exactly how speed may have an effect. During his activity, it was quite hard to tell whether the novice used this misleading scheme. He kept on interacting with the process by pressing the speed button but failed to check the results of his activity on the frame. To conclude, this misleading scheme does not seem dangerous: it was hardly used and the expert operator was able to deconstruct it by himself. Indeed, simply informing the operators about it should be sufficient.

7.2 | Opportunities for action

On the contrary, that the novice operator hardly ever took any measurements during the stretching task is more problematic. One cannot deny that this lack of control over the results of his activity is questionable. It could indicate that the operator was disengaged from this task. Such disengagement may also be revealed through the low cognitive cost devoted by the operator to the treatment of the task. Indeed, he barely focused on the task itself. The task may have been too costly for him, in which case he did not feel it was worth devoting too many resources to its completion. According to Hoc and Amalberti (2007), the operator adjusts his cognitive control, depending on his feeling of situation mastery. With regard to the resources he has at his disposal, he will change the performance he judges acceptable and then use a more or less costly treatment to adjust the origins (intern or extern) and nature (symbolic or subsymbolic) of the data. During the stretching task, the novice operator had few resources. He had no external help, and his representation of the situation seemed inefficient. Finally, he had few opportunities for action. He could not experiment or modify certain elements of his activity, such as the tool or the machine's programs, because of the prescribed nature of the task, which was set by the factory.

These elements have been considered in existing literature related to the capability framework and enabling environments (Falzon, 2005, 2008). Such environments offer opportunities to facilitate learning and skills development and for action and autonomy. In this factory, however, it appeared to be difficult to develop one's own competences for this task. Moreover, a novice operator also worked on the frame during the manual calibration task. During this step, he had total control of his activity. He could choose the actions to be taken and execute them in the way he wanted, using his experience of this task. Thus, it seems logical that this operator chose to transfer the decision making and control activity to the manual calibration tasks over which he had better control, albeit at a cost to performance.

A simulation tool would, therefore, appear to be a good way to solve this issue. First, it would allow a trial-and-error process. The operators could then test their theories without risk, that is, without impairing the real process. Actually, in the current configuration, the operators cannot test their hypotheses concerning the causes of a fault by trying different configurations of programs and tools. The operators, especially the novice operators, have to follow the protocol. If they believe that a fault is caused by the program, they cannot change it because access is restricted; if they believe a fault is caused by a tool, they cannot change it because the number of different tools is limited. A simulation would allow different programs and tools testing. For the factory, there are no risk of frame spoiling: many different programs can be tested until the good one is found. Besides, a proper simulation could provide the operators with objective arguments supporting their insight that a change of tools is needed.

Second, a simulation tool would allow the presentation of a coherent visualization of the problem at stake, particularly in terms of how the different elements extracted from the abstraction hierarchy interact with one another to impair or improve the process. For example, the simulation tool could help to visualize the physics of elastic return by allowing the manipulation of the inner characteristic of the frame, the chosen stretching program, and the frame final state. In this condition, we can expect that the inner characteristics of the frame would become a key indicator to set the stretching program.

7.3 | Avoid the misleading scheme related to batch homogeneity and favor a more anticipative organization

The second misleading scheme related to concerns about batch homogeneity and, more generally, to frame homogeneity within a supplier reference. This scheme was observed for both the novice and the expert operators. Moreover, the expert operator actually used it during his activity. In the factory, the whole stretching task was organized according to this scheme, whereas operators were meant to use one program and one set of tools for a frame reference. They were also supposed to measure the results after the stretching step, rather than before. Finally, even though the frame supplier gives the average inner characteristics for a batch, these elements were never used to adjust the programs, which were fixed within a frame reference.

The use of this misleading scheme obviously implies that the first frame of a batch will be spoiled in order to test whether the program and tools are efficient. It may be possible to avoid this wastage by using a simulation tool and taking measurements before stretching.

However, this would necessitate in-depth changes to the current organization of the task and the operators' activity. Indeed, the operators would have to take measurements and check the mean values of the inner characteristics for each batch before the first stretching step. They would then use the simulation tool to see whether the standard tools and program used for the reference did actually work for this batch. The simulation should be able to predict whether the tools' dimensions are correct for the current frame. After the first stretching step, the operators would then take measurements again and adjust the simulation according to the observed values. Each frame may be different; thus, the results observed after the first stretching could be used to better evaluate the inner characteristics of the current frame by adjusting the observed values and the values given by the simulation. This would avoid having to waste the first frame.

Eventually, the remediation actions may take two different forms. First, the simulation tool could lower the cost of using a pertinent scheme, making the operators more likely to use it. Second, training aimed at inhibiting the misleading scheme (Moutier, Angeard, & Houdé, 2002) may be undertaken, as such a scheme may be persistent, especially if it is commonly used in various contexts, that is, if it has an ontogenetic origin. As this reorganization may be costly, it is important to estimate the effect of the misleading scheme on performance to assess whether such significant changes are necessary.

8 | IMPLICATIONS OF MISLEADING SCHEMES

Our study has revealed that operators performing the stretching and bending task on this machine used two different misleading schemes.

The first misleading scheme relates to the speed of the machine. Indeed, the operator can press a speed button to slow or increase the machine's speed. This misleading scheme is specific to this task, as it is related to the machine used. Such specific and tool-related misleading schemes could be encountered in any domain. Therefore, it seems interesting to study operators' misleading schemes whenever recurrent defaults appear in the final product or a new tool, device, or machine is introduced into the fabrication process. Actually, such schemes could impair the appropriation of the new element and, as a consequence, have negative effects on production. It seems pertinent, therefore, to identify and prevent them through appropriate training.

The second observed misleading scheme relates to the homogeneity of frame batch. This misleading scheme is not linked to the machine but to a more global cognitive functioning. Indeed, the tendency to give equal treatment to elements that share common salient characteristics is already known (Tirosh & Stavy, 1999). This second scheme, which relates to batch homogeneity, may have an adaptive purpose, allowing cognitive cost savings. Such schemes may then be observed in other domains, including daily life, where the task is applied to objects that vary but share common salient characteristics; for example, driving in a different country or in a different vehicle. In industry, this misleading scheme can be observed in any dynamic situation in which there is a lack of information about the object and feedback about the results. This dearth of information drives the operators to rely on their former encounters with the task to make decisions.

In the task presented in this study, it was difficult to identify which element led to specific faults, because many different variables were at stake. Some of them were not even made available to the operators. This may explain why even expert operators persist in using this misleading scheme. This persistence merits further investigation in other settings.

Misleading schemes have been deeply studied from a didactic point of view. Here, they were revealed to be pertinent for addressing both design and conception and activity analysis in general, as they may impair formation and production.

9 | CONCLUSION

This article presents an explorative field study and the theoretical questions that arose during its investigation. Indeed, the field study aimed to respond to an industry-based problem: how to help operators to avoid fault in an aluminium frame after stretching and bending. Recommendation for a tool simulating the physical process underlying the task was required. The activity analysis showed that operators tended to disengage from the process. More importantly, they used misleading schemes that impaired the process. To deal with this issue, recommendations are i) to give operators more possibilities of action using the simulation tool, and ii) to prevent the apparition of the misleading schemes through training.

This study gives rise to some interesting theoretical questions related to the status of misleading schemes in industry and in ergonomics in general. Indeed, as observed in this study, such schemes may be present in other circumstances, tasks, or factories. Not only could such schemes impair performance in general, but they could also interfere with the introduction of new technology, new tools, and new organizations. Thus, it may be of interest to evaluate their presence and their effect during ergonomic intervention.

Finally, this study highlights the differences between misleading schemes and two closely related concepts often used in ergonomics. The first one is a heuristic (Gigerenzer & Gaissmaier, 2011), because misleading schemes also mean that some of the information available is ignored. In this study, we showed that the misleading scheme was always used by the expert, who made no attempt to verify its validity. On the contrary, a heuristic is a clearly identified domain of validity (Dreyfus & Dreyfus, 1980; Hoc, 2005); that is, as an expert, he should have been able to determine whether a heuristic is efficient. Another important concept is related to error (Reason, 1990). An error may be a consequence of the use of a misleading scheme, whereas the misleading scheme itself is an inappropriate way to organize an activity. These studies may help us to better understand and investigate the necessary conditions for the use and manifestations of misleading schemes. For instance, one of the questions that remains unanswered here is whether a misleading scheme is able to persist when all the necessary resources are provided, that is, when all the relevant information and knowledge are represented through the use of a simulation tool.

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