Eye Tracking Experiments on Process Model Comprehension: Lessons Learned

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Abstract. For documenting business processes, there exists a plethora of process modeling languages. In this context, graphical process models are used to enhance the process comprehensibility of the stakeholders involved. The large number of available modeling languages, however, aggravates process model comprehension and increases the knowledge gap between domain and modeling experts. Upon this, one major challenge is to identify factors fostering the comprehension of process models. This paper discusses the experiences we gathered with the use of eye tracking in experiments on process model comprehension and the lessons learned in this context. The objective of the experiments was to study the comprehension of process models expressed in terms of four different modeling languages (i.e., BPMN, eGantt, EPC, and Petri Net). This paper further provides recommendations along nine identified categories that can foster related experiments on process model comprehension.

Keywords: Process Model Comprehension, Eye Tracking, Experiment

1 Introduction

During the last years, a lot of research was conducted to enhance our understanding of working with process models. Besides their creation, particular emphasis has been put on their reading and understanding, i.e., on *process model comprehension*. Despite extensive research in this field [5, 19, 51], there still exists a knowledge gap between inexperienced process stakeholders and modeling experts. Usually, process models are not fully understood by all involved stakeholders, who neither have experiences with process modeling nor deeper knowledge of any specific process modeling language. This raises the challenging question to identify the factors fostering the comprehension of process models. One promising approach for coping with this challenge is to perform experiments.

This paper contributes to the field of business process model comprehension through experimental research. It discusses the experiences we gathered and the lessons we learned when performing a series of experiments on process model comprehension relying on eye tracking. In detail, the experiments conducted dealt with process model comprehension in connection with four process modeling languages (i.e., *BPMN*, *eGantt*, *EPC*, and *Petri Net*). In these experiments, we measured the eye movements of subjects in order to assess their approaches of comprehending process models. On one hand, we want to enable a comparison between different process modeling languages. On the other hand, the perceived pros and cons of respective modeling languages shall be unraveled. To the best of our knowledge, only few approaches have considered eye tracking for such comparison in the context of business process model comprehension so far. Notably, during the preparation, execution, and analysis of the experiments, several difficulties have been encountered and various issues emerged. They constitute valuable lessons learned that will allow for optimizations of future experiments on process model comprehension.

As another valuable insight for researchers performing experiments on process model comprehension, this paper introduces nine categories C1 - C9 of the lessons learned. Process models are related to specific scenarios and, hence, familiarity of individuals with the considered process scenario varies (C1). Following this, the understanding (C2) and creation (C3) of process models can be juxtaposed. Afterwards, a discussion on the structuring and layouting (C4) of the respective process models is provided, followed by the presentation of the used process modeling languages (C5) and their specific characteristics (i.e., basic modeling elements (e.g., activities) (C6) and modeling constructs (e.g., gateways (C7)). Finally, individuals (C8) as well as measurement methods (C9) are addressed.

The remainder of this paper is organized as follows: Section 2 presents the experimental setting. The gathered experiences and the lessons learned from the experiments are presented in Section 3. Related work is discussed in Section 4, whereas Section 5 concludes the paper with a summary and an outlook.

2 Experimental Setting

The lessons learned refer to experiments on process model comprehension that use *eye tracking* as measuring technique. Moreover, eye tracking constitutes a cost-effective and unobtrusive method to gain deeper insights into human cognitive processes [40]. Thereby, it measures eye movements in response to a visual stimulus (e.g., picture). Most common types of evaluated eye movements are *fixations*, *saccades*, and *gaze paths* [43]. Fixations constitute eye movements of very low velocity at a specific point during a stimulus. Saccades, in turn, constitute quick eye movements. Note that during saccadic eye movements, no visual information is perceived. In turn, a *gaze path* represents the chronological order of fixations and saccades the eyes take while analyzing a stimulus. Furthermore, an *area of interest (AOI)* constitutes a manually defined subregion in the presented stimulus. Generally, it can be used to extract metrics, specifically for these defined regions. For tracking and recording the eye movements in our experiments, the SMI iView X Hi-Speed system[1] was used, which allows for accurate eye tracking, even over a longer time of recording. The tracking appliance was placed in front of a monitor that presents the stimuli (i.e., process models) to the subjects;

[1] `http://www.smivision.com/en/gaze-and-eye-tracking-systems/products/iview-x-hi-speed.html`

eye movements were tracked at a sampling rate of 240 Hz. The eye tracking data collected during the experiments were analyzed, visualized, and exported with SMI BeGaze software. The latter enables behavioral and gaze analyses [39].

In the controlled eye tracking experiments, the subjects had to comprehend 12 different process models and were asked to answer several comprehension questions related to these process models. At the same time, their eye movements were tracked and recorded. In more detail, the process models were expressed in terms of *BPMN* [44], *eGantt* [47], *EPC* [45], and *Petri Net* [46], respectively. Subjects, in turn, needed to comprehend three process models for each modeling language reflecting different levels of difficulty. More precisely, the process models were subdivided into three levels of model difficulty (i.e., easy, medium, and hard). The simple process models solely contain basic elements (e.g., activities, start event) of the respective modeling language. Furthermore, with rising level of difficulty, the total number of elements was increased and new elements provided by the respective modeling language, not introduced before, were added. After each process model had been analyzed by the subjects, the latter had to answer four *true-or-false* comprehension questions (cf. Fig. 1). The questions solely referred to the semantic content of the process models and were used to evaluate whether or not subjects interpret the process models correctly. Thereby, correct answers have been stored with '1' and incorrect answers with '-1', whereas '0' corresponds to 'I am uncertain' answers. We are aware of the fact that the comprehension of process models without any guidance (e.g., purpose) is uncommon. However, in the first experiments we wanted to investigate the approaches for the pure comprehension of process models. In general, one of the objectives was to evaluate the overall performance of subjects, when being confronted with different modeling languages in the context of process model comprehension. The results obtained may serve as contributions allowing a meaningful comparison between various process modeling languages in the future.

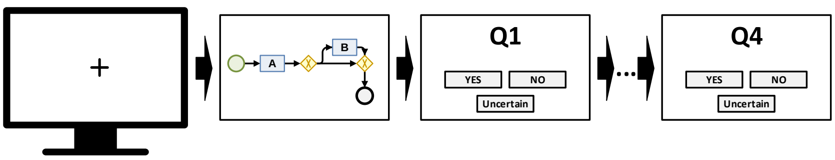


Fig. 1: Overall Procedure of the Experiments

Concerning the overall procedure of the experiments (cf. Fig. 1), at the beginning of the experiment, for one second, a fixation cross was displayed on the center of the monitor. The cross was used to fixate the gaze of the subjects on a defined point on the monitor. Afterwards, the process model was presented to subjects, who could take as much time as they wanted for model comprehension. Moreover, subjects were told that they should perform the experiments as fast as possible, but at the same time as careful as possible. Following the model comprehension task, four related questions were presented of which only one was shown on the monitor at the same time. While answering the questions, it was not possible to reinspect the studied process model. The experimental procedure was repeated for all considered process models.[1]

Regarding the considered process models and their level of difficulty, Table 1 presents the number of subjects that studied the respective process models as well as the results (i.e., means) they delivered by showing the required time to comprehend the models (i.e., duration time in ms). Furthermore, the response times for answering the comprehension questions (in ms) as well as corresponding answering scores (i.e., absolute frequency of correct answers) are illustrated. Finally, the total number of fixations, saccades, and total gaze path lengths (in px) are presented.

			Modeling Languages			
	Category	**Item**	**BPMN**	**eGantt**	**EPC**	**Petri Net**
Difficulty Easy	Subjects	Number of Subjects	29	30	30	30
	Comprehension	Comprehension Duration	35270	31840	36120	36930
		Response Time	6210	5710	4890	6580
		Answering Score	0.66	0.58	0.92	0.78
	Eye Tracking	Number of Fixations	112	105	103.93	110
		Number of Saccades	101	94	89	95
		Gaze Path Length	19958	14858	15169	19128
Difficulty Medium	Subjects	Number of Subjects	29	30	28	28
	Comprehension	Comprehension Duration	53910	34860	53100	49170
		Response Time	7640	6160	7790	8290
		Answering Score	0.62	0.74	0.75	0.63
	Eye Tracking	Number of Fixations	191	119	171	151
		Number of Saccades	180	108	153	133
		Gaze Path Length	35682	19653	26442	21562
Difficulty Hard	Subjects	Number of Subjects	28	29	27	28
	Comprehension	Comprehension Duration	68940	58270	86520	76860
		Response Time	9170	8360	8240	8230
		Answering Score	0.27	0.53	0.54	0.23
	Eye Tracking	Number of Fixations	230	169	278.93	282
		Number of Saccades	215	146	252	254
		Gaze Path Length	41503	20556	40602	52377

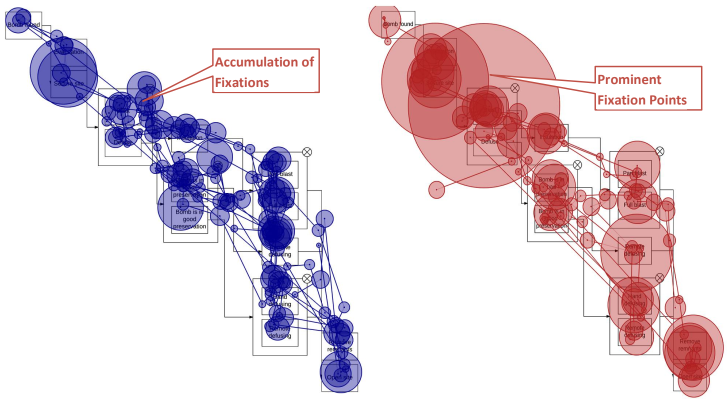
Table 1: Obtained Experimental Results

The results indicate that, with rising level of model difficulty, overall comprehension performance is decreasing. In particular, the duration time needed for model comprehension increases, in this context. Furthermore, the response times for answering comprehension questions increase as well with rising level of model difficulty, whereas the corresponding answering scores decrease with rising level of difficulty. Finally, the total number of fixations and saccades increase, depending on the level of difficulty. Hence, the lengths of gaze paths are increasing as well in this context.

Fig. 2 presents selected evaluation screenshots of the used SMI BeGaze software. The evaluation provides information about fixations and saccades of the

[1] Sample material downloadable from: `www.dropbox.com/sh/our1qp7vkpv020i/AABr3a24DwCKjWAU_2DDCIWMa?dl=0`

difficult eGantt process model. Thereby, circles represent subjects fixations. The size of a circle, in turn, corresponds to the subjects dwell time. Finally, the concatenation of fixations and saccades generates the gaze path.



(a) Gaze Path of Subject 1 (b) Gaze Path of Subject 2

Fig. 2: Examples of Subjects Gaze Path

In Fig. 2 (a), several accumulations of fixations on specific areas of the process model become visible. In Fig. 2 (b), in turn, prominent fixation points can be identified. To be more precise, the corresponding subject spent much time at these points. Furthermore, Fig. 3 presents the results we obtained when analyzing specific areas of interests of a process model. It further indicates the complexity of analyzing eye tracking data. In particular, such analysis allows for an extensive evaluation of eye movements. For example, the number of fixations is higher in areas of interests comprising XOR gateways compared to areas with AND gateways. Moreover, the XOR represented by the area of interest XOR_2 contains more fixations and highest average dwell time.

3 Lessons Learned

This section discusses the lessons learned during the eye tracking experiments in which we compared different process modeling languages. In particular, these lessons are grouped into nine categories C1 - C9 (cf. Fig. 4).

C1 - Familiarity with Process Scenarios

The kind of scenario considered in the context of an experiment might influence experimental outcomes as it might be easier for individuals to deal with scenarios from an application domain they are familiar with (e.g., pizza delivery vs. bomb defusing). Accordingly, with increasing familiarity with the scenario,

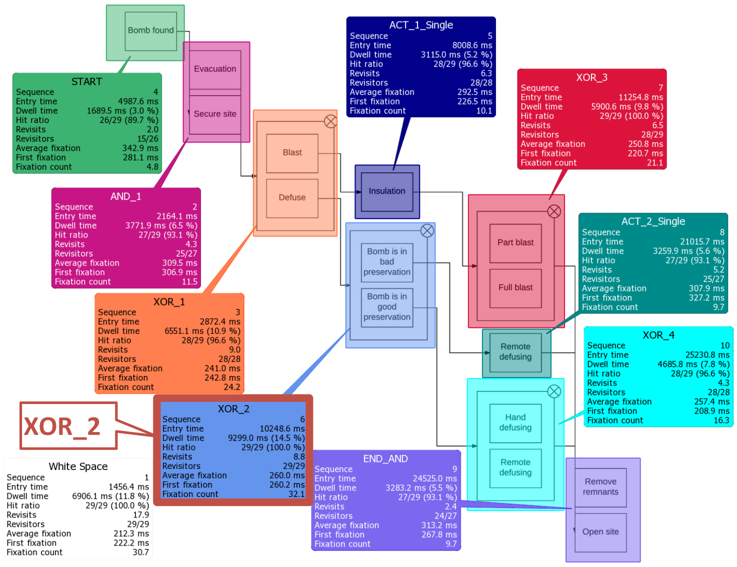


Fig. 3: Defined Areas of Interest in a Process Model

the cognitive load in the working memory might become lower. By contrast, if individuals are unfamiliar with a process scenario, they first need to get an overview of the scenario they are confronted with. Consequently, comprehending process models related to a scenario an individual is unfamiliar with requires a higher cognitive load. To reduce this *familiarity bias* in the experiments we conducted, the subjects were confronted with process models representing different scenarios. For example, subjects needed about the same time for comprehending a process model describing a shopping process (cf. Table 1; BPMN - Medium) and a process dealing with the editing of a wikipedia article (cf. Table 1; EPC - Medium); i.e., for these two scenarios, no differences could be observed. However, if the process models are exceeding a certain level of model difficulty, in turn, the working memory of individuals might be confronted with an information overload resulting in a reduction of overall understanding. For example, the more complex BPMN model describes a pizza delivery process, i.e., a process which can be considered as well-known. However, the subjects were facing difficulties regarding the comprehension of respective model that might be owed to the level of model difficulty.

C2 - Understanding of Process Models

In general, the understanding of process models (i.e., *process model comprehension*) is a complex matter as the information contained in these models need to be decoded and captured by an individual. Consequently, comprehension constitutes a cognitive process trying to establish relations between available information on objects and events in the long term memory, together with in-

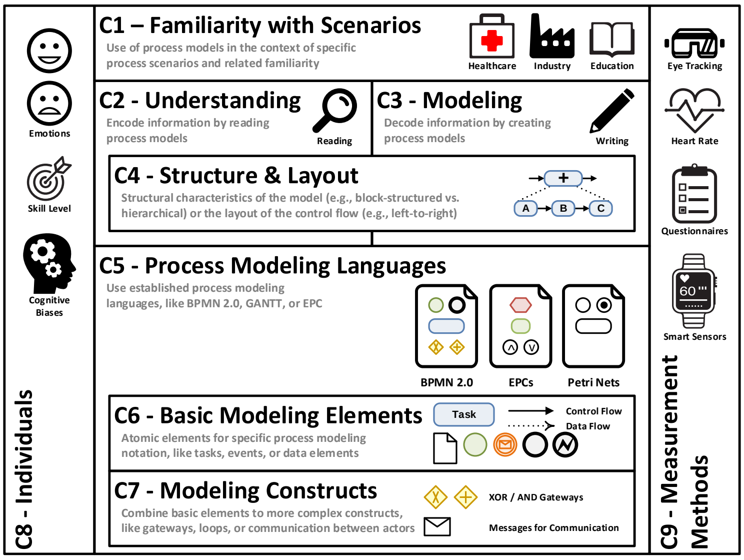


Fig. 4: Categories Describing the Experimental Setting

formation perceived at the moment from the sensory, working, or short term memory. Concerning process model comprehension, individuals must handle the complexities of parsing the relevant syntactic, semantic, and pragmatic information of a process model expressed in terms of a particular language. The easier and clearer this information is presented, the more positive will be the impact on process model comprehension (e.g., Cognitive Load Theory (CLT)). In our experiments, several policies for comprehending a process model could be identified. Independent from the experience a subject has with process modeling, all policies are similar in the first comprehension iteration (i.e., after having a first glance at the process model). More precisely, subjects visually discover all elements of a process model in an element-to-element procedure. Usually, this procedure begins with the start element of a process model. During the second comprehension iteration, subjects follow different policies (e.g., jumping back and forth between specific modeling constructs or elements). For this reason, the comprehension questions might serve as an indicator to evaluate the efficiency of the comprehension policies. The identification of concrete patterns for process model comprehension will be addressed in future work.

C3 - Modeling of Process Models

The modeling of processes deals with the encoding of information of a process model. This activity, in turn, involves various factors as well as specific cognitive processes that can be neglected in process model comprehension. The conducted experiments so far, focused on the comprehension of process models. However, the lessons learned in this context might apply to process modeling as well.

C4 - Structure & Layout

The processes were presented as flat (i.e., non-modularized) models to the subjects; i.e., no sub-processes were used. Additionally, all models were block- structured [41], which fits well with one of the seven process modeling guidelines [16]. In general, one needs to investigate to what extent a particular structuring of a process model influences its comprehensibility. Furthermore, all process models were created in a way to be either read from left-to-right or top-to-bottom. However, one of the process models (i.e., Petri Net - Hard) was designed using a very ramified structure (i.e., sequence flows running in all directions). Regarding the results depicted in Table 1, it is unclear whether or not ramified structures affect the comprehension of process models.

C5 - Process Modeling Languages

Table 2 presents the answering scores (i.e., means) for all considered process models and their respective levels of difficulty.

		Modeling Languages			
		BPMN	**eGantt**	**EPC**	**Petri Net**
Difficulty	**Easy**	0.66	0.58	0.92	0.78
	Medium	0.62	0.74	0.75	0.63
	Hard	0.27	0.53	0.54	0.23

Table 2: Answering Scores Obtained in the Experiments

The results indicate that the comparison of process modeling languages with respect to model comprehension allows for interesting insights. For example, one might expect that the answering scores are decreasing with rising level of model difficulty. Interestingly, in this context, the results related to eGantts constitute a counterexample, i.e., an increase of the answering scores for the process models with an easy and medium level of difficulty can be observed. Moreover, one might expect that for all process modeling languages a comparable decrease can be observed with rising level of difficulty. However, regarding the BPMN answering scores obtained from the process models reflecting an easy and medium level of difficulty, the results are different in orders of magnitude compared to EPC and Petri Net.

C6 - Basic Modeling Elements

During the experiments it turned out that process models with an explicit start and an end symbol foster process model comprehension. Initially, subjects are trying to locate a start symbol in the process model. Usually, the start symbol is assumed to be on the left or upper left side of the process model. However, if subjects are unable to identify a start symbol on the assumed positions in the process model, their gaze paths become directionless, due to the search of the start symbol. The same effect can be observed with respect to end symbols.

C7 - Modeling Constructs

As opposed to basic elements, more complex modeling constructs (e.g., gateways) seem to be difficult for individuals. In the experiments, the main challenge subjects were facing concerns the identification of the semantic meaning of the presented modeling constructs (e.g., AND gateways). A common approach was to identify the meaning of a construct by considering the described process scenario in detail. Furthermore, split-and-join gateways (i.e., XOR) appear to be particular challenging for subjects. Referring back to Fig. 3, Fig. 5 presents a binning chart showing the proportion of fixations over the duration needed for process model comprehension. Fig. 5 indicates that subjects spend more time with studying the first gateway (i.e., the first gateway along the reading direction) compared to the subsequent other. The same effect can be observed in the binning charts of other process models. In this context, it makes no differences whether an AND or an XOR gateways appears first. As a next step, we want to provide an extensive and direct comparison between the specific modeling constructs (i.e., AND vs. XOR) of the respective languages as well as their effect on model perception and interpretation of individuals.

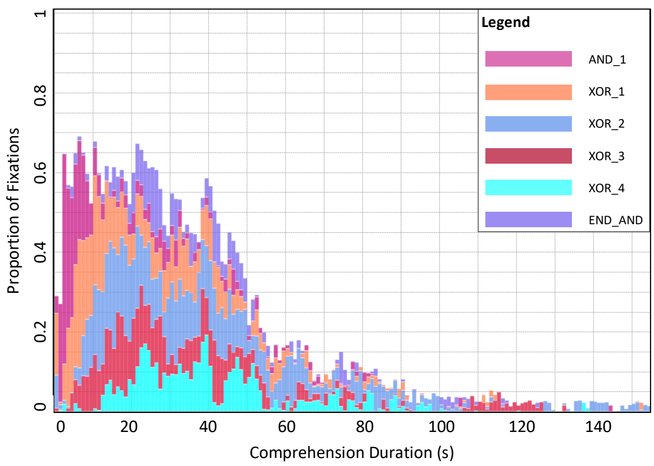


Fig. 5: Binning Chart for Gateways in a Process Model

C8 - Individuals

The experiment revealed that the used process models, which were expressed in different process modeling languages, can be intuitively understood by subjects, independent from their modeling experience. In particular, the performance of the subjects regarding the comprehension of easy process models is satisfactory (cf. Table 1). However, with increasing level of model difficulty, the performances of the subjects are decreasing to the same extent. Moreover, we assumed that subjects being experienced with process modeling are more efficient regarding process model comprehension. Finally, subjects without any modeling experience are facing the same challenges than experienced ones regarding process model comprehension. The reasons for this might be manifold, ranging from *personal factors* (e.g., familiarity with the provided scenario) to *modeling factors* (e.g., process model quality). The identification of those factors that might positively or negatively influence the individuals regarding process model comprehension will be subject of future experiments. So far, a decrease of the performance can be observed with rising level of model difficulty (cf. Table 1). Future experiments will particularly focus on the cognitive processes of individuals. For example, considering *cognitive psychology* (e.g., Split Attention Effect), *cognitive biases* (e.g., Framing), or specific *emotional states* (e.g., Alexithymia).

C9 - Measurement Methods

The use of eye tracking in the context of research on process model comprehension has led to tangible results. In the experiments, we obtained valuable insights into how subjects understand process models that are expressed with different modeling languages. The evaluation of fixations and saccades as well as the gaze paths observed during process model comprehension reveal interesting facts on particular policies for process model comprehension. For future experiments, first of all, a broader distribution of the subjects based on their experience in process modeling (i.e., novices, intermediates, and experts) needs to be evaluated. So far, we have only investigated the differences between novices and intermediates (i.e., individuals with moderate experience in process modeling). However, the involvement of experts might reveal significant differences. Second, the comprehension questions had to be answered after studying the respective process model without the possibility to reinspect them. Therefore, the models had to be memorized by subjects bearing the risk that given answers were guessed due to wrong memorizations. The mental process of memorization, in turn, raises various issues that need to be considered. We therefore will make use of the visual *Split Attention Effect*, presenting the process model and corresponding comprehension questions at the same time. This approach will allow us to obtain more precise observations regarding areas of interest (cf. Fig. 3). In addition, it will allow for statements in case the answers to related questions correlate with a subjects' gaze path in the defined area of interest. Finally, basic elements (e.g., activities) and constructs (e.g., AND) should be comparable across all modeling languages. Therefore, future experiments will focus on measurement methods other than eye tracking, as known from *cognitive neuroscience* (e.g., smart sensors) and *psychology* (e.g., Construal Level Theory).

4 Related Work

This section discusses related work along the presented categories (cf. Fig. 4).

C1 - Familiarity with Process Scenarios. In a study dealing with various process model representations (i.e., flattened vs. modularized), [6] found no evidence that domain knowledge influences process model comprehension. Despite different cognitive abilities, learning styles and motives as well as policies of individuals, [7] could not confirm an influence of domain knowledge on process model comprehension. Assessing the use of a particular process modeling language, [8] shows that domain-specific modeling experience and knowledge have no significant effect on the understanding of process models.

C2 - Understanding of Process Models. Regarding process model comprehension, considerable research was conducted in the last decade. Comparing BPMN models with a textual notation (i.e., a written use-case), [14] presents a significant increase regarding model comprehension. More precisely, when reading the textual models, all individuals show an increase, whereas for BPMN models, solely the experienced individuals show an increase. [17] investigates whether there are significant differences in terms of understanding, depending on the process model representation (i.e., text vs. graphical model). An extensive discussion of a series of experiments related to process model comprehension is presented in [34]. Finally, the SEQUAL framework provides various aspects of process model quality fostering the comprehension of suchlike [36].

C3 - Modeling of Process Models. Common to the work related to category C3 is its focus on the resulting process model, i.e., the product of process modeling. [2] evaluates the process of process modeling itself. Furthermore, [15] focuses on how process models are created. The different steps a process modeler accomplishes during the creation of process models are discussed in [54].

C4 - Structure and Layout. [48] identifies visual features and metrics fostering the creation of understandable process models. A set of propositions on the effects of the notational aspects on the improvement of process model comprehension is presented in [49]. In turn, [50, 52] discuss how modularity enhances process model expressiveness. Taking end user preferences into account, [53] demonstrates the importance of structuring process models.

C5 - Process Modeling Languages. Several frameworks exist dealing with the quality issues of different kinds of conceptual models (e.g., process models). In this context, [4] presents frameworks for evaluating the quality of conceptual models. In turn, [35] investigates how different representations affect model comprehension. In this context, it is shown that modeling languages, which allow for concurrent activities (i.e., parallel branches) are difficult to understand. In an empirical investigation, [38] elaborated UML Activity Diagrams as the most versatile modeling language in the context of process model comprehension. To be more precise, the latter outperformed the comprehension of models expressed in terms of EPC or BPMN.

C6 - Basic Modeling Elements. [27] conducted an experiment comparing the effects different flow directions have on model comprehension. In particular, it was shown that readers adapt well to uncommon reading directions. In turn, [28] investigates human understanding of process models, trying to identify influence factors with respect to "local" comprehensibility (e.g., activities, sequences) in process models. A comparison of the understanding of imperative and declarative process models is presented in [30].

C7 - Modeling Constructs. [21] demonstrates in an experiment that the interpretation of process models benefits from gateway constructs (i.e., AND), due to the perceptual discriminability effect of the latter. Especially, this effect is evident for complex process models. Specific thresholds for gateway complexity metrics can be found in [22]. These metrics serve as guidelines for novices to classify process models in specific level of understandability. in turn, [23] provides a structural equation model, depicting the relationships between flow orientation in a process model, quality of process models, and business process redesign success. The equation model shows that flow orientation constitutes a key factor. Finally, [24] investigates basic symbol sets of various process modeling languages, showing that notational deficiencies concerning perceptual discriminability and semiotic clarity have a negative impact on process model comprehension.

C8 - Individuals. [11] investigates preferences of individuals (i.e., cognitive styles) regarding alternative process representations, which have a positive effect on process model comprehension. In the context of business process variability, an empirical user study shows that neither complexity nor expertise in process modeling have a significant impact on process variant modeling [12]. Experience in modeling, as a crucial skill of individuals having a significant impact on the success of process modeling, is described in [13]. In turn, [25] provides evidence that the chosen process scenario representation form as well as individuals' characteristics result in similar levels of understanding, independent from whether subjects are confronted with familiar or unfamiliar process scenarios.

C9 - Measurement Methods. Eye tracking is increasingly used in research related to process modeling. [32] shows that reading process models changes pupil dilation as evidence for higher mental effort. Findings on how eye tracking might contribute to a deeper understanding of process models can be found in [33]. In [18], the existing research gap concerning the factors influencing process model comprehension tasks is investigated using eye tracking. [1] identifies performance improvement opportunities by determining the performances of individuals regarding different types of comprehension tasks. Finally, [9] proposes the use of visual cues in process models to improve their overall comprehensibility.

Regarding the comparison of process modeling languages, there exists several work. A review of process modeling languages can be found in [42]. Using a generic meta-model as benchmark, [29] evaluates seven modeling languages and their corresponding concepts. Further, [56] classifies existing process modeling languages. Finally, a literature review of the state-of-the-art on empirical research on process model comprehension is presented in [55].

5 Summary and Outlook

This paper gave insights into experiences we gathered in and the lessons learned from experiments on process model comprehension using eye tracking. To obtain these insights, process models in terms of four different modeling languages (i.e., BPMN, eGantt, EPC, and Petri Net) were considered in the experiments. To structure our discussion on the lessons learned, the gained insights were grouped into nine categories (cf. Fig. 4). Using this categorization, we are going to conduct a series of experiments to enhance the understanding on how the overall comprehension of process models can be fostered. Additionally, we will focus on process model creation (i.e., the process of process modeling). Thereby, particular emphasis will be put on *human factors*, especially on the cognitive processes involved. Altogether, using eye tracking for comparing different process modeling languages offers valuable insights into how process models are comprehended by individuals.

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