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How Novices and Experts Understand Hierarchies in Business Process Modeling

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Abstract

Conceptual models are essential for successful IT implementation, as they concisely represent the system's component structures, behavior, and relationships. However, for conceptual models to fully realize their potential, they must be understood. To this end, hierarchy has been employed in business process modeling to enhance understanding of complex models. Prior research has proposed a two-component framework to explain the effects of hierarchy on understanding. Drawing on empirical data, this work extends this framework by investigating the influence of expertise on the understanding of hierarchical business process models. Our findings indicate that experts and novices benefit from hiding task-irrelevant information in subprocesses, with experts benefiting significantly more than novices. Additionally, experts profit more from recognizing familiar patterns in subprocesses than novices. Based on our results, we propose two principles for designing hierarchy and suggest future research avenues.

Keywords: Business Process Modeling, Hierarchy, Expertise, Information Hiding.

Introduction

Business process models help to design, implement and improve process-aware information systems (Dumas et al., 2005). Throughout the life-cycle of information systems, business process models are used to continuously adapt the system to the dynamics of the domain (Strong and Miller, 1995). Therefore, graphical notations such as the Business Process Modeling and Notation (BPMN) or the Event-driven Process Chain (EPC) can be used to capture current tasks, events, states, and flow logic (Reijers and Mendling, 2011). Once business process models are developed, they serve not only in the design or adaption of information systems design or adaption (Maruping and Matook, 2020) but also for problem-solving and communication among stakeholders (Reijers *et al.*, 2011). For example, project members with varying process modeling expertise use business process models to gain a shared understanding of the domain (Davies et al., 2006). Furthermore, new employees use these models as an introduction to the domain.

Yet, business process models must be understood to foster problem-solving and communication (Dikici et al., 2017; Mendling et al., 2012). Prior research indicates that understanding these models is challenging, particularly for stakeholders that are novices (Dikici et al., 2017; Störrle et al., 2014; Turetken et al., 2016). These challenges stem from complexity resulting from the domain and from the way the information is represented in the model (Figl et al., 2010). Domain complexity is what stakeholders seek to understand when approaching a domain with business process models. In this regard, reducing domain complexity would inhibit domain understanding (Störrle et al., 2014). In contrast, complexity resulting from how information is presented through the graphical notation should be held low as graphical notations are only means to transport domain complexity (Figl et al., 2010). There has been research to reduce complexity resulting from how information is presented. This research relates to producing a cognitive fit between the domain and the graphical notation (e.g., Agarwal et al., 1996; Vessey and Galletta, 1991), to ensure good layout (e.g., Störrle, 2011; Störrle et al., 2014), and manage complexity by using hierarchy (e.g., Andaloussi et al., 2020; Reijers et al., 2011b; Zugal et al., 2011). While there are generally accepted rules on how a cognitive fit and good layout can be obtained (e.g. Becker et al., 2000; La Rosa et al., 2011; Mendling et al., 2010), there are contradictory results on how hierarchy can be used to manage complexity.

Hierarchy is introduced in business process models by dividing information from larger flat models into smaller parent and subprocesses (Zugal et al., 2015) so that, e.g., subprocesses are presented below the parent process. During the last few years, many process modeling notations have implemented the notion of hierarchies, such as BPMN and EPC. Prior research has detected an effect of hierarchy on understanding business process models (Reijers et al., 2011b; Turetken et al., 2016; Zugal et al., 2015; Turetken et al., 2020) and has suggested a two-component framework to explain these effects (Zugal et al., 2011, 2015). This framework includes the components abstraction and fragmentation. **Abstraction** relates to information hiding and pattern recognition. Both are associated with the positive effects of using hierarchy (Zugal et al., 2015). Information hiding allows for filtering less relevant information and hiding it in subprocesses so that stakeholders can concentrate on more relevant information by focusing on one or few parent or subprocesses that contain the relevant information, e.g., for the task at hand. Pattern recognition allows for separately displaying typical patterns in visually distingt parent and subprocesses so that hierarchy highlights these patterns and allows for better recognition. **Fragmentation** describes the adverse effects on understanding hierarchy that result from visually separating information in parent and subprocesses. Displaying these processes separately, stakeholders need to switch attention between these visually separated processes to understand the whole model and integrate the information (Zugal et al., 2011, 2015). Hierarchy impacts positively if abstraction (i.e., benefits) outbalances fragmentation (i.e., costs).

Prior research has used the two-component framework as the theoretical basis for investigating the impact of hierarchy on understanding models, e.g., with different complexity (Reijers et al., 2011b; Turetken et al., 2016; Zugal et al., 2015; Turetken et al., 2020). However, apart from a few exceptions (e.g., overweight of fragmentation and hence costs in small models), the two-component framework did not reliably allow for predicting the counterbalance between abstraction (benefits) and fragmentation (costs) when using hierarchy. Accordingly, prior research reports that hierarchy can have a positive influence (Reijers et al., 2011b), negative influence (Cruz-Lemus et al., 2008; Turetken et al., 2016; Turetken et al., 2020), or no influence at all (Cruz-Lemus et al., 2005). Thus, except for small models, the two-component framework does not sufficiently explain the influence of hierarchy on understanding. In one of the two-component model experiments, Turetken et al. (2020) varied the model readers' expertise by including subjects with no and with some business process modeling knowledge. They found an influence of prior business process modeling knowledge on task effectiveness (i.e., scores). The importance of business process modeling competence for understanding business process models has also been recognized as an essential factor by (Reijers and Mendling, 2011; Mendling et al., 2012; Turetken et al., 2017). However, prior business process modeling experience has not been investigated for the individual components of the framework.

This paper aims to investigate the influence of expertise in business process modeling on understanding hierarchy using the theoretical basis of visual expertise, which is appropriate for a vision-inventive task such as reading a business process model (Petre, 1995). Visual expertise represents the maximal adaptation to the requirements of a vision-intensive task (Gegenfurtner and van Merriënboer, 2017). It is gained through repetitive exposure to domain-related material for which expertise builds up. With growing visual expertise, model readers develop a perceptual advantage that helps them perceive far more information than less experienced stakeholders can (Reingold and Sheridan, 2011). Therefore, we think model readers' visual expertise influences their understanding of hierarchy in business process models. Without knowing how visual expertise impacts understanding hierarchy, modelers do not know how to use hierarchy to manage the complexity of business process models sufficiently. This paper investigates how visual expertise impacts the understanding of hierarchy. We contribute to theory and practice. For theory, we extend the two-component framework for the expertise dimension. The extended framework helps to understand the evidence of prior research. This understanding directly contributes to practice, as modelers can manage the complexity of business process models based on how stakeholders require the information and can thus make business process models more effective for communication and problem-solving.

Visual Expertise

Visual expertise has mainly been independently researched with eye-tracking for chess (e.g., Charness et al., 2001; Reingold et al., 2001) and radiation (e.g., Krupinski, 1996; Nodine and Kundel, 1987). In 2011, the results of these two domains were integrated into a review (Reingold and Sheridan, 2011). The review concludes that visual expertise is associated with a global processing advantage in medicine (Nodine and Kundel, 1987) aligns with what is referred to as perceptual advantage in chess (Reingold et al., 2001). Based on these advantages, expert radiologists benefit from a more efficient scan path (e.g., Krupinski and Borah, 2006; Krupinski, 1996), require fewer fixations and saccades (e.g., Kocak et al., 2005; Manning et al., 2006) and spend a more significant proportion of time on relevant areas, e.g., abnormalities (e.g., Kundel, 1974; Nodine et al., 2002). Chess experts spend more time on relevant figures (Charness et al., 2001; Reingold and Charness, 2005) and decide more rapidly and accurately whether a chess piece is attacked (Saariluoma, 1985). For the chess domain, De Groot assumed in the middle of the last century that chess mastery relies on efficiently encoding the scene rather than on thinking ahead for the next moves (De Groot, 1978; De Groot, 1946). This was taken up by Chase and Simon, who suggest that due to extensive practice, chess experts develop associations between groups of chess pieces and their schemas in long-term memory (LTM, Chase and Simon, 1973a, 1973b). By doing so, chess experts develop access to many LTM schemas estimated to amount to up to 300,000 schemas (Gobet and Simon, 2000). Furthermore, the complexity and flexibility of the experts' LTM schemas differ from those of novices (Gobet et al., 2001; Gobet and Jackson, 2002) so that they can cover an amount of information for which novices would require several schemas (Gobet and Simon, 2000). The number, complexity, and flexibility of schemas all influence the reasoning process. When reading a visual graphic, readers usually fixate on a particular part, which is then reflected in working memory (WM; Gobet, 2005). Based on this reflection, readers create pointers between WM and their schemas in LTM to interpret this reflection with what can be remembered from LTM (Gobet, 2005). The number of pointers was estimated to be around 7+/-2 (Miller, 1956) and was more recently limited to four (Cowan, 2010). Having a fixed number of pointers for reasoning activities, experts can integrate more information from LTM for their reasoning processes, as they have access to more complex and flexible schemas than novices. Hence, experts can recall an amount of information from LTM that is far beyond what novices can recall (Gobet and Simon, 2000).

Assuming that it is true that experts have access to more complex and flexible schemas than novices, Reingold and Sheridan concluded that, based on the amount of information that readers perceive from a fixation, their fixation point varies (Reingold and Sheridan, 2011), thus suggesting different fixation points for experts and novices. While novices rather fixate on single objects, experts locate their fixations to maximize the information gain, for instance, by focusing between objects. In fact, evidence suggests that chess experts tend to fixate along the edges of squares (De Groot et al., 1996) or on empty squares (Reynolds, 1982), while novices focus more on the pieces. Beyond having access to more complex and flexible schemas, experts further gain information from an increased visual span. While novices usually require foveal vision, experts can also use parafoveal and peripheral vision to detect information (Gegenfurtner et al., 2011). For example, Carmody et al. found that when presenting visual graphics under exposure conditions that preclude further eye movements, expert radiologists can detect nodules that are 15 degrees away. In contrast, less experienced persons only detected nodules 10 degrees away (Carmody et al., 1980). In summary, experts perceive information with an increased visual span and process information using more complex and flexible schemas so that they can easily outperform novices.

Research Model

Whenever hierarchy is present in business process models, fragmentation costs (with switching information and information integration) and abstraction benefits (with information hiding and pattern recognition) are stimulated and hence impact the mental resources required to understand the model (Zugal et al., 2015). However, abstraction and fragmentation can influence mental resources to a varying degrees. For instance, hierarchy in small models typically results in less significant abstraction benefits compared to more complex models, due to the limited positive impact of information hiding and pattern recognition. As fragmentation will also occur if the model is small, fragmentation will likely outbalance abstraction (Zugal et al., 2015). Hence, hierarchy is likely to impact understanding negatively. In addition to the model size, we believe that visual expertise influences abstraction and fragmentation. In the following, we make predictions about the effect of visual expertise on abstraction and fragmentation:

Effects of visual expertise on abstraction. Novices have not yet developed a perceptual advantage and cannot perceive as much information as experts (Gobet and Simon, 2000). Perceiving a limited amount of information, novices are likely to profit from hiding less relevant information to the task at hand in some subprocesses while condensing the more relevant information in others. In contrast, experts can perceive and process a large amount of information (Gobet and Simon, 2000; Reingold et al., 2001) so that they may not need information hiding as much as novices to complete the task. In fact, experts, with their increased visual span, may even perceive information in subprocesses as unhidden (Gegenfurtner et al., 2011). This leads to our first proposition:

P1: Novices profit more from information hiding than experts.

In contrast to novices, experts have often been exposed to typical business process patterns that are now likely reflected through their LTM schemas (Gobet and Simon, 2000). Hierarchy in business process models can be used to separately display typical patterns in subprocesses, highlighting these patterns. Thus, experts can be supported to efficiently match the business process patterns of the subprocesses with their LTM schemas. As novices are not likely to access many LTM schemas that reflect many typical business process modeling patterns (Gobet and Simon, 2000; Gobet et al., 2001), pattern recognition is expected to be less relevant for novices. Based on these observations, we propose the following:

P2: Experts profit more from pattern recognition than novices.

Effects of visual expertise on fragmentation. While abstraction reflects the benefits of using hierarchy, fragmentation reflects its costs. Fragmentation results from switching attention and information integration (Zugal et al., 2015). Due to their perceptual advantage from a larger visual span (Gegenfurtner et al., 2011), experts are likely to rely less on attention switching than novices to perceive the same amount of information. Consequently, they are likely to benefit from reduced attention-switching costs when perceiving parent and subprocess information simultaneously. Additionally, we hypothesize that information integration costs decrease as expertise increases. If model readers are experienced with reading hierarchical process models, they have already integrated many subprocesses into their parent process and have built access to procedural knowledge that novices do not yet have access to (Gobet et al., 2001). Therefore, we posit that as expertise grows and fragmentation costs decrease, the benefits of abstraction become more likely to outweigh the costs of fragmentation. Based on these observations, we propose the following:

P3: Abstraction outbalances fragmentation (i.e., hierarchy impacts positively) more for experts than novices.

In this paper, we investigate these propositions using a laboratory experiment. Notice that this paper mainly explores the influence of expertise on abstraction (P1 and P2). While we've touched upon the potential effects of fragmentation, it isn't the primary focus. Instead of delving into fragmentation, we present propositions regarding the overarching influence of hierarchy in P3. In the following, we operationalize the propositions into hypotheses and summarize the factors required to test the hypotheses. For P1, we require model readers with different levels of visual expertise for business process models (factor 1). We operationalize this factor by integrating expert and novice model readers into the experiment as has been done by (e.g., Reijers et al., 2011; Zimoch et al., 2017). We assume that expert model readers have gained substantial visual expertise when reading domain-related material. When reading this material, model readers could build access to more complex LTM schemas related to this material so that they are likely to be able to process domain-related material even from a wider visual angle (Stark et al. 2016; 2018). For operationalizing information hiding, we distinguish between two types of tasks: Local and global tasks. The two-component framework suggests that hierarchical models rather allow to benefit when solving local tasks, while flat models rather allow to benefit when solving global tasks (Zugal et al., 2015, 2011). In hierarchical models, local tasks just require perceiving information from one subprocess or the parent process, while the remaining information can be hidden in other subprocesses. In contrast to local tasks, global tasks require perceiving information dispersed across several subprocesses so that information from at least two subprocesses needs to be perceived and integrated (Andaloussi et al., 2020). Hence, to investigate information hiding, we refer to the distinction of the task type using global and local tasks.

For investigating pattern recognition (P2), we include layout as a factor for the following reason: Visual expertise in business process modeling is accumulated through repeated exposure to business process models. Thereby, model readers are likely to gain access to LTM schemas that reflect the patterns they often encounter in business process models (Stark et al. 2016; 2018). When exposed to business process models, it's reasonable that readers develop LTM schemas reflecting those models in accordance with established modeling conventions. These schemas are likely to be reinforced when reencountering a certain business process model pattern presented in a clear, well-structured layout, as opposed to the same pattern depicted in a poorly organized layout. In this regard, we typically encounter information, such as presented in Figure 1a, that uses a good layout instead of information presented in the same bad layout as in Figure 1b. Hence, we propose that well-known patterns inhibiting a good layout are rather reflected in an expert's LTM so that they are likely to encode these patterns more efficiently than those characterized with a bad layout. Referring to esthetic metrics for graphs (e.g., Petre, 2006; Purchase, 2014) that have been adapted for business process modeling (e.g., Bernstein and Soffer, 2015; Figl and Strembeck, 2015; La Rosa et al., 2011), we operationalize layout using good and bad layout by varying line crossings, edge bends, symmetry, use of locality and reading direction. Note that we still use a uniform size and a grid-like arrangement of the elements so that model elements can still be distinguished and the process flow can still be perceived.

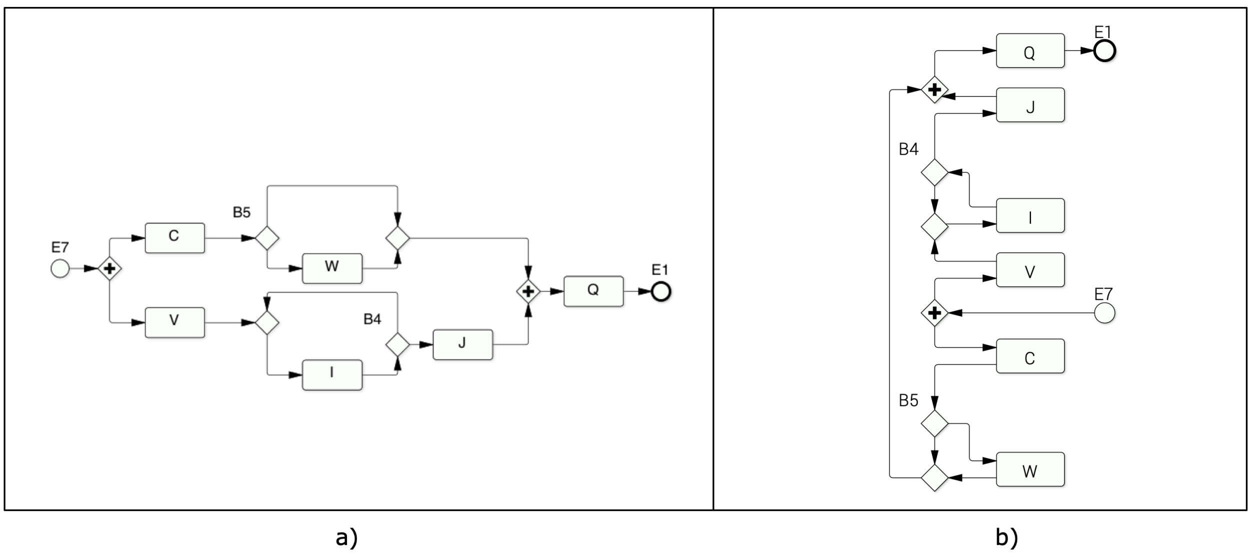


Figure 1. Examples of subprocesses with a) good layout and b) bad layout.

While P1 and P2 investigate abstraction, P3 aims to examine the counterbalance of abstraction and fragmentation for novices and experts. We propose that for experts, fragmentation outbalances abstraction more than for novices. For this investigation, we require the factor modularization. Modularization is operationalized using flat models and models composed of parent and subprocesses as used in (Andaloussi et al., 2020; Petrusel et al., 2016; Zugal et al., 2015). This factor is required whenever hierarchy is directly investigated by contrasting flat and hierarchical models. While we use factors such as task, visual expertise, layout, and modularization as independent variables, we use understanding as the dependent variable and operationalize this variable using comprehension scores and time as has been a common operationalization (e.g., Mendling et al., 2019; Reijers et al., 2011). Table 1 summarizes the factors as well as their operationalization for P1-3.

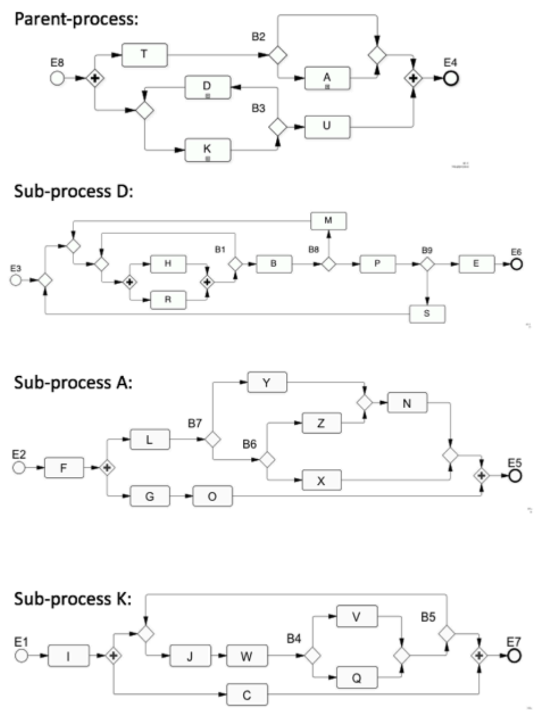
Proposition	**Hypothesis**	**Independent Variables**	**Dependent Variables**
P1: Novices profit more from information hiding than experts.	H1a: When answering global in contrast to local questions, novices increase comprehension scores more than experts. H1b: When answering global in contrast to local questions, novices decrease time more than experts.	Visual Expertise Task Type	Comprehension Accuracy, Response Time
P2: Experts profit more from pattern recognition than novices.	H2a: When answering questions with patterns that often reoccur in subprocesses in contrast to questions with patterns that seldom reoccur, experts increase comprehension scores more than novices. H2b: When answering questions with patterns that often reoccur in subprocesses in contrast to questions with patterns that seldom reoccur, experts decrease time more than novices.	Visual Expertise Pattern type	
P3: Abstraction outbalances fragmentation (i. e., hierarchy impacts positively) more for experts than novices.	H3a: When answering questions for hierarchical instead of for flat models, experts can increase scores more than novices. H3b: When answering questions for hierarchical instead of for flat models, experts can decrease time more than novices.	Visual Expertise, Modularization	

Table 1. Summary of Propositions and Hypotheses.

Experiment

The experimental material comprises six paper models, five each consisting of a parent and three subprocesses, and one flattened model. One of the models with parent and subprocesses is used to train the participants, while the other models directly contribute to investigating the hypotheses. For each model, eight questions were developed (see Figure 2). We balanced the difficulty of the questions and models. For example, to balance the difficulty of questions, we included four global and four local questions for each hierarchical model. To balance the difficulty of the models, we included subprocesses with good and bad layouts varying symmetry, locality, and reading direction (see Figure 1a and b). Furthermore, we controlled the number of tasks, events and gateways within the models and used single letters instead of text within the task to reduce the time required to search the relevant tasks for the question at hand. Next to the models, the participants also obtained a legend of the syntax of the elements used in the model as well as an explanation of the patterns used within the models (e.g., parallel and alternative tasks and optional tasks).

We invited novices and experts to take part in the experiment. Novices were invited to participate in the experiments within their classes and include undergraduate university students. These students so far had no experience with reading business process models. As experts, we invited professors, postdoctoral researchers, scientific assistants, and practitioners that we knew had gained a lot of experience by developing and reading business process models. Due to the limited time of these experts, we arranged to conduct the experiment with one or two experts and one experiment instructor. Before we started the experiment, experts and novices were asked to answer questions pertaining to personal characteristics and their level of expertise. For example, in determining expertise, we asked which process modeling languages the person has worked with, the time that they have worked with the process modeling languages they indicated before, how many process models in each language have been read and developed within the last twelve months as well as the previous month. Furthermore, we asked the participants to indicate their sex, age, profession, and education.



Nr.	Question	Y	N	Time
1	Having reached the end of the process, is it possible that V has been executed more often than Q?			
2	Can E more often be executed than C?			
3	Can H and M be executed in parallel?			
4	Having reached the end of the process, is it possible that K has been executed more often than U?			
5	Can Z and D be executed in parallel?			
6	Can the end of the process be reached without executing B?			
7	Can B5 determine how often C will be executed?			
8	Does E need to be starting after L?			

Figure 2. Example Model and Questions of the Experiment (note: the original Questions are in German as the Experiment took place in Germany)

Before starting the experiment, we conducted a pilot test with two experts and two novices. In this pilot test, we asked the participants to answer the questions and indicate the perceived difficulty of each question. After they completed answering the questions, we further reviewed the reasoning process together to see how they reached their results and to identify possible misunderstandings. We started with 11 questions per model and reduced the number of questions per model to 8 based on the pilot test results. The reduction helped us to obtain a set of questions with comparable perceived difficulty, which had been answered without misunderstandings. When conducting the experiment, one instructor first explained the procedure, as detailed below. The participants were asked to fill in their personal details and details about their degree of experience with business process models. Then, they were asked to complete a training model together with the instructor to enable them to understand the procedure. In the following, the participants were asked to answer the questions of the first experimental model. Please note that the order of models assigned to the participants was randomized to balance training effects, which usually occur in such within-subject designs. After the experiment, one of the authors coded the material in terms of time required and scores based on a sample solution developed and checked by all authors.

Results

Forty-four novices and 22 experts participated in the study. Most experts were academics, while a small number were software developers. These experts have worked on average for 38.3 months (minimum of 36 months and maximum of 360 months) with at least one process modelling grammar. The students were business information systems students. They had worked on average 9.1 months (minimum one month and maximum of 60 months) with UML, EPC, or another process modelling grammar. The results for H1a and b are summarized in Table 2, the scores were measured as the percentage of total scores. When comparing the performance on global questions to that on local questions, novices could increase 8 % of their comprehension scores, reaching 81 % for global questions and 89 % of the scores for local questions. Experts could increase 7 % of their comprehension scores by reaching 88 % of their scores for global questions and 95 % for local questions. Both groups increase their percentages of comprehension scores when moving from global to local questions. Two variants of the t-test were used to test the hypotheses. The differences within the group were calculated with the dependent t-test and the differences between the groups with the independent t-test under the assumption of equal variances. A p-level of 0.05 was assumed for all tests. Although novices have a slightly higher increase in comprehension scores as predicted, this difference is not significant. Hence, we found no significance for H1a. However, we found a significant difference for H1b and hence the time required to answer the questions. When comparing the performance on global questions to that on local questions, novices could decrease the time from 28.22 seconds to 23.57. In contrast, experts could decrease the time by 7.17 seconds. To our surprise, the difference is significant, but contrary to our predictions, as experts can significantly reduce more time than novices due to information hiding.

Proposition	**Hypothesis**	**Group**	**Mean of global Ques-tions** *Std*	**Mean of local Ques-tions** *Std*	**Mean of difference for each group** *Std* (p-value of paired t-Test)	**Mean of difference of increase between groups** (p-value of t-Test) [Hedges' g]
P1: Novices profit more from information hiding than experts.	H1a: When answering global in contrast to local questions, novices **increase scores** more than experts.	Novices	81 % *0.11*	89 % *0.11*	+ 8 % *0.11* (0.000)	1 % (0.614) [9.68]
		Experts	88 % *0.10*	95 % *0.06*	+ 7 % *0.09* (0.003)	
	H1b: When answering global in contrast to local questions, novices **decrease time** more than experts.	Novices	28.22 s *6.10*	23.57 s *4.72*	- 4.65 s *3.09* (0.000)	2.52 s (0.010) [0.69]
		Experts	37.88 s *7.88*	30.70 s *6.71*	- 7.17 s *4.58* (0.000)	

Table 2. Results for H1a and H1b – Effects of Expertise on Information Hiding (s = seconds)

The results for H2a and H2b are summarized in Table 3. When answering questions without patterns in contrast to questions with patterns, novices could increase 9 % of their comprehension scores by reaching 80 % for questions without patterns and 89 % for questions with patterns. In contrast, experts could increase 3 % of their comprehension scores. As predicted, both groups increased their comprehension scores percentages when moving from questions unrelated to patterns to those related to patterns. However, we did not find a significant difference between the groups for comprehension scores. While there is no significance for H2a, we found a significant difference for H2b, hence the time required to answer the questions. When answering questions unrelated to patterns in contrast to those related to patterns, novices could decrease the time from 26.60 seconds to 26.02 seconds and hence achieve a slight difference of 0.58 seconds. In contrast, experts could decrease the time by 3.88 seconds. Hence, we found a significant difference for both groups that supports H2b and a medium effect size of 0.55 using Hedges' g.

Proposition	**Hypothesis**	**Group**	**Mean of no pattern** *Std*	**Mean of pattern** *Std*	**Mean of difference for each group** *Std* (p-value of paired t-Test)	**Mean of difference of increase between groups** (p-value of t-Test) [Hedges' g]
P2: Experts profit more from pattern recognition than novices.	H2a: When answering questions with patterns that often reoccur in subprocesses in contrast to questions with patterns that seldom reoccur, experts **increase scores** more than novices.	Novices	80 % *0.14*	89 % *0.10*	+ 9 % *0.14* (0.000)	7 % (0.073) [51.17]
		Experts	91 % *0.10*	94 % *0.08*	+ 2 % *0.13* (0.417)	
	H2b: When answering questions with patterns that often reoccur in subprocesses in contrast to questions with patterns that seldom reoccur, experts **decrease time** more than novices.	Novices	26.60 s *6.84*	26.02 s *6.10*	- 0.58 s *5.24* (0.468)	3.30 s (0.039) [0.55]
		Experts	37.03 s *10.62*	33.16 s *7.54*	- 3.88 s *7.32* (0.021)	

Table 3. Results for H2a and H2b – Effects of expertise on pattern recognition. (s = seconds)

The results for H3a and H3b are summarized in Table 4. When comparing the performance on questions related to flat models to those related to hierarchical models, novices could increase 2 % of their comprehension scores by reaching 81 % for questions related to flat models and 83 % for questions related to hierarchy. In contrast, experts decreased 1 % of their comprehension scores, reaching 87 % of their scores for questions related to flat models and 86 % for questions related to hierarchy. We did not find a significant difference between the groups for comprehension scores. When answering questions related to flat models in contrast to those related to hierarchy, novices could decrease the time from 26.16 seconds to 25.52 seconds. Experts could decrease the time for 1.70 seconds by requiring 36.14 seconds for questions related to flat models and 34.44 seconds for questions related to hierarchy. However, we did not find a significant difference between the groups.

Proposition	**Hypothesis**	**Group**	**Mean of flat** *Std*	**Mean of hie-rarchy** *Std*	**Mean of difference for each group** *Std* (p-value of t-Test)	**Mean of difference of increase between groups** (p-value of t-Test) [Hedges' g]
P3: Abstraction outbalances fragmentation (i.e., hierarchy impacts positively) more for experts than for novices.	H3a: When answering questions for hierarchical instead of for flat models, experts can **increase scores** more than novices	Novices	81 % *0.13*	83 % *0.14*	+ 2 % *0.17* (0.437)	1 % (0.527) [6.44]
		Experts	87 % *0.10*	86 % *0.10*	+ 1 % *0.12* (0.825)	
	H3b: When answering questions for hierarchical instead of for flat models, experts can **decrease time** more than novices.	Novices	26.16 s *5.69*	25.52 s *5.87*	- 0.64 s *5.25* (0.422)	1.06 s (0.515) [0.17]
		Experts	36.14 s *6.79*	34.44 s *6.56*	- 1.70 s *7.74* (0.315)	

Table 4. Results for H3a and H3b – Effects of expertise on hierarchy. (s = seconds)

Figure 3 shows the scatter plot, which plots the achieved score on the X-axis and the time required in seconds on the Y-axis. The black dots are the results for the experts, and the gray squares are the results for the novices. Furthermore, three correlation coefficients were calculated for the correlation between points and seconds overall ($r = 0.138$, $p = 0.270$) and then for experts only ($r = -0.311$; $p = 0.011$) and novices only ($r = -0.007$; $p = 0.953$). For the experts only, the regression coefficient becomes significant at the 0.05 level. The coefficient is negative, which means that the more time an expert took to answer the tasks, the fewer points he received. From the correlation coefficients for all and for the novices themselves, no conclusion can be drawn about a possible correlation.

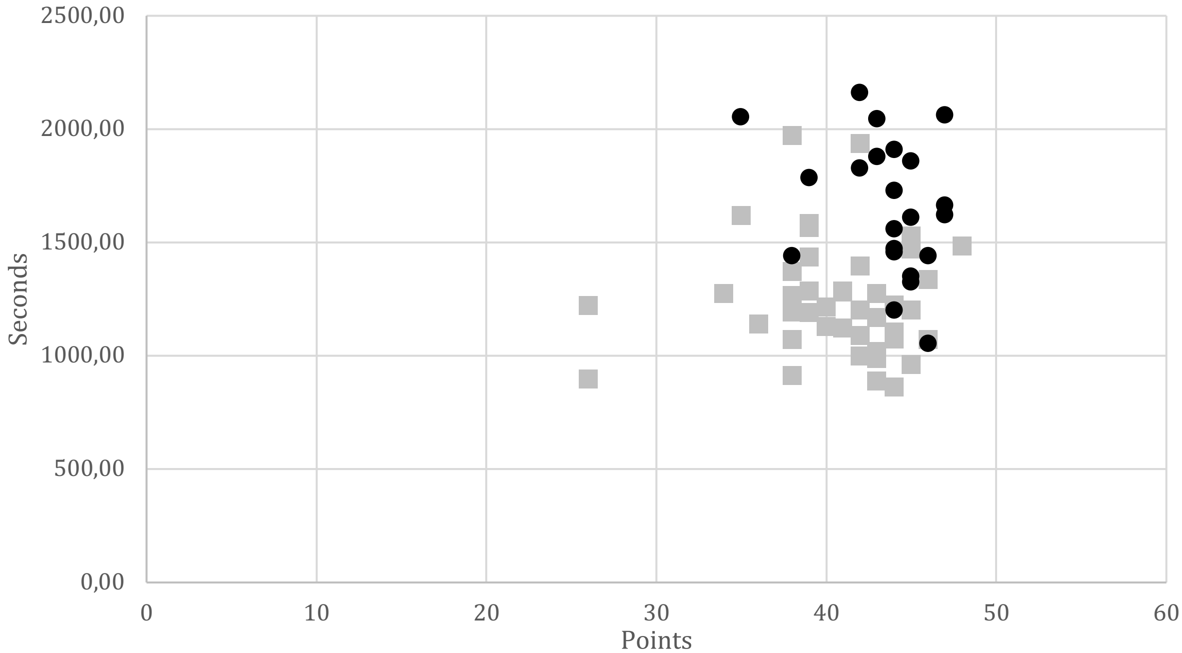


Figure 3. Scatter plot between the achieved score and time required in seconds to complete the tasks. Legend: Black dots = results of the experts. Gray squares = results of the novices.

Discussion

Findings

Our results shed light on the influence of expertise on understanding hierarchy in business process models, particularly for the abstraction component, and the associated benefits of using hierarchy (Zugal et al., 2015, 2011). Abstraction benefits of using hierarchy stem from hiding information irrelevant to the task in (other) subprocesses and condensing the relevant information in one or few subprocesses that the model reader investigates for solving the task. Our results indicate that information hiding is relevant for experts and novices. In fact, information hiding is significantly more relevant for experts than novices, contrary to our predictions. Another benefit of using hierarchy is pattern recognition. In line with our predictions, the results indicate that pattern recognition is more relevant for experts than novices. Novices have not yet learned many patterns related to business process modeling and thus have not yet access to many LTM schemas related to typical business process modeling patterns. This is why novices are not likely to match patterns that have a distinct position within a subprocess. In contrast, experts have already gained access to many business process-related patterns reflected within their LTM schemas. So, they likely match typical patterns exposed in subprocesses easier with their LTM patterns than patterns distributed among larger flat processes that appear less highlighted. Table 5 summarizes these effects of expertise on hierarchy.

Our findings reveal a different impact of experts and novices on time and scores. For novices, enhancements of hiding relevant information in the same subprocesses predominantly affect scores. In contrast, most significant impact for experts lies in the realm of time efficiency. Thus, experts demonstrate greater elasticity concerning time, whereas novices exhibit a higher elasticity in scores. Such insights have implications for research and practice. For research, combined metrics like 'Score per second' offer more meaningful insights. For practice, these nuances between experts and novices can guide the customization of tools and training modules. For novices, emphasis can be placed on improving clarity and comprehension, ensuring they can achieve higher scores. Meanwhile, for experts, optimizing processes and interfaces to reduce time consumption becomes paramount.

	Abstraction (benefits from using hierarchy)	
	Information Hiding	**Pattern Recognition**
Experts	**Relevant** Information hiding is relevant for experts to a more significant extent than for novices. Explanation: Although experts can perceive and process a great amount of information due to having access to many Business Process Modeling-related schemas in their LTM, they are likely to profit from perceiving information that needs to be perceived and processed together for solving a task in a separate subprocess.	**Relevant** Experts profit from pattern recognition. Explanation: Experts have already learned many Business Process-related patterns and are likely to perceive typical patterns as being highlighted through a distinct place in subprocesses.
Novices	**Relevant** Also, novices benefit from information hiding, although not as much as experts. Explanation: Novices have not yet developed the capacity to access many LTM schemas related to Business Process Modeling and do not profit from information intake from a wide visual angle. Therefore, they are likely to profit from information hiding so that they can focus on task-relevant information, e.g., in one or few subprocesses.	**Relevant but to a lesser extent.** Novices do not profit from pattern recognition. Explanation: Novices have not yet learned many patterns of business process models. So, typical patterns do not appear to novices as highlighted through a distinct place in subprocesses.

Table 5. Effects of Expertise on Abstraction Benefits of Using Hierarchy. Note: Causal Relations in the Explanations were not Subject to our Investigation

As indicated in the result section, our hypothesis H1b was significant but to the contrary. At first, this was surprising to us, as experts profit from information intake from a larger visual span as has been supported, e.g., in radiology (Carmody et al., 1980). This capability of taking more information in has been explained by experts having access to many more flexible LTM schemas related to their area of expertise (Gobet and Simon, 2000). For the context of Business Process Modeling, expertise may be translated into experts having access to many flexible LTM schemas that they can use to match the schemas of the material they are presented with. By exploiting this perceptual advantage, they can perceive more information even from a wider visual angle. We assumed that the wider visual angle allows for taking in information from several subprocesses. However, the results can be interpreted that taking information in from several subprocesses is not possible even for experts. In the following, we propose an explanation of why information hiding is significantly more relevant for experts than novices. This explanation includes two aspects: the experts' visual span and their tendency to search for a relevant region.

In regard to the visual span, prior research noted that novices tend to fixate on figures in chess, while experts fixate along edges or on empty squares (De Groot et al., 1996; Reynolds, 1982). In line with this, Business Process Modeling experts may focus along edges or on empty spaces between elements to maximize their information intake so that they can perceive and process as many tasks, events, and states as possible. However, based on our results, we presume that the expert's visual angle may not be as wide as would be required to take in elements from several subprocesses, which we had initially assumed. More likely, their visual angle allows for taking in several elements of only one subprocess. As a result, both experts and novices have to newly fixate when switching to another subprocess. Our results also suggest that experts profit significantly more than novices from a situation in which information is hidden so that the relevant information can be found within one subprocess. This may be explained by the expert's capacity to maximize information intake by fixating in between subprocess elements to take as much information of the subprocess in as possible. In contrast, novices will likely also profit from finding relevant information in subprocesses due to having shorter saccades and, so, reducing the required number of fixations to find relevant information within a subprocess. Nonetheless, they will likely require more fixations than experts to find the relevant information in subprocesses due to their limited capacity to take information in. This explanation may be subject to a future investigation. Whether this explanation is feasible may be tested using an eye-tracking experiment, which has already been evaluated as being a valuable tool for investigating perceptual and cognitive processes in reading business process models (Bera et al., 2019).

In regard to the experts' tendency to search for a relevant region, experts may have developed a perceptual shortcut due to their learning history. For example, depending on the model complexity, Haisjackl et al. (2016) noted that when approaching a business process model, subjects first try to get an overview. This tendency has also been described in (Petrusel et al., 2017) and (Petrusel and Mendling, 2013). When answering specific understanding questions, experts at a certain time in their reading process most likely detect an area, which is referred to as relevant region as this area contains relevant information that model readers require to analyze for solving the specific task. If the relevant region is embedded within one subprocess, this behavior is facilitated. So, experts may profit from hiding less relevant information in other subprocesses and highlighting relevant regions that are most interesting in one subprocess.

Implications for using hierarchy in business process modeling

The effect of expertise on reading hierarchical business process models has several implications for designing hierarchy in business process models. First, as information hiding is relevant both for experts and novices, it appears that business process modelers should use information hiding as a principle for introducing hierarchy. This means that information, which needs to be perceived together for solving potential tasks, should to be included in the same subprocess. In case relevant information for one task is distributed across several subprocesses, more fixations with longer saccades are likely, which may lead to requiring more time or solving problems and answering questions less accurately. Once hierarchy is introduced by dividing information into different subprocesses so that information that needs to be perceived together is retained within the same subprocess, the model can further be optimized in regard to highlighting patterns within subprocesses. As our results suggest, both experts and novices tend to profit from highlighting patterns within subprocesses, although we found a stronger impact for experts. In this regard, we recommend that designers of business process models use a clear and effective layout in their subprocesses so that model readers can match the patterns of the subprocesses with those they access through their LTM schemas. This optimization of the layout includes adhering to commonly referred to guidelines from (e.g., Bernstein and Soffer, 2015; Figl and Strembeck, 2015; La Rosa et al., 2011) who postulate avoiding line crossings and edge bends, exploit symmetry, use of locality and adhere to the commonly used reading direction from left to right or from top to bottom. These two principles can be summarized as follows:

Modularization Principle 1*: Use hierarchy to structure information within subprocesses so that information that is required to be perceived together for solving tasks or answering questions can be found in the same subprocess.*

Modularization Principle 2*: Use a clear and effective layout within the subprocesses so that experts can match patterns they have already learned easier with those highlighted in the subprocesses.*

Interpreting related literature through the lens of the results

This study investigates the impact of expertise on information hiding and pattern recognition in hierarchical business process models. Turetken et al. (2020) directly investigated the influence of prior business process modeling knowledge on understanding hierarchy including novice model readers and intermediate experts. Consistent with our findings, they observed sores tend to increase with growing business modeling expertise. Also, in line with our results, the authors found a trend that task efficiency partly decreases with increasing expertise. Turetken et al. (2020) explain this effect by a "likely tendency of participants with lower levels of knowledge on process modeling and notation to engage less actively in a thorough deliberation of the models and tasks given to them". Hence, in line with Turetken et al., (2020), we could not detect a significant effect that hierarchy impacts more positively for experts than for novices, in general.

In this study, we further investigated the influence of visual expertise on the individual components of the two-component framework, which is often used to explain how hierarchy impacts on understanding business process models. In the following, we discuss the impact of expertise on the individual components of the two-component framework, relating our results previous research. Prior research has mainly focussed on investigating information hiding (Reijers et al., 2011b; Turetken et al., 2016; Zugal et al., 2015). Turetken et al. (2016) mainly included domain experts that were novices to business process modeling. In contrast, Zugal et al. (2015) and Turetken et al. (2020) included experts and intermediate experts, while Reijers et al. (2011b) included experts in the experiment. For novices, Turetken et al. (2016) report that scores for global questions do not significantly differ between flat and hierarchical models, while scores from local questions are significantly lower for hierarchical than for flat models. Hence, their novice model readers do not profit from information hiding in hierarchy. For experts, Reijers et al. (2011b) report significantly higher scores for local questions in hierarchy than for corresponding questions in flat models and thus summarize that experts profit from information hiding. Also, Zugal et al. (2015) report that for global questions, mental effort was significantly lower for hierarchical than for flat models. The findings of (Reijers et al., 2011b) and (Zugal et al., 2015) are consistent with our results, indicating that experts benefit from information hiding in hierarchical business process models. Yet, the results of (Turetken et al., 2016), who included novice model readers differ from ours. Turetken et al. (2016) suggest that for local questions, modularization reduces effectiveness. Our results, however, indicate that also novices profit from information hiding, although not as much as experts.

Limitations and Future Research

So far, this research has examined the abstraction component of the two-component model. However, expertize may also impact on the fragmentation component as highlighted in the proposition section. Future research may investigate the impact of expertize on fragmentation. Furthermore, this research has focused on using parent and subprocesses. However, hierarchy may not necessarily include parent processes. According to Strahringer (1996), modularization can also occur without an explicit integration layer (i. e., parent process) so that subprocesses are integrated with each other. This research has focused on hierarchy operationalized through parent and subprocesses. Hence, future research may also investigate further types of modularization. Furthermore, we think that the results of this work may also contribute to modularization in general. Whenever perceiving modularized information is necessary for solving a task or to foster understanding, expertise regarding the material that needs to be perceived impacts understanding. In this regard, future research may also focus on generalizing the results of this work for modularization in general and not related to business process models. Given the agile emphasis on cross-funktional expertise and its role in successful project ourcomes (Kautz and Zumpe 2008; Matook et al., 2016), future studies could also dvelve into how varying levels of expertise in agile environments influence the understanding and effectiveness of different modularization strategies. This study is subject to further limitations that can be improved by the following measures: A higher number of participants could sharpen the reliability of the results. Furthermore, future experiments could become more realistic if the real names of the tasks are used instead of the letters. Also, open-ended questions could increase the task difficulty and require more intensive engagement with the content for both groups. Another analysis possibility would be to analyse the change in time as a percentage instead of the absolute changes. A second limitation includes the confinement of our study to a controlled experimental environment, which may not entirely capture the nuances and complexities of real-world scenarios. While our findings provide insights into the understanding of hierarchical business process models, the absence of practical, on-ground validation may impact their applicability. Cross-validating our results through expert interviews could have enriched our understanding and offered a more comprehensive perspective. The intricate dynamics of real-world business processes, influenced by various organizational factors, might introduce variables not accounted for in our controlled setting. As such, while our findings serve as a foundational understanding, their direct transferability to practical scenarios may require further investigation and validation.

Conclusion

This paper has investigated the influence of expertise on understanding hierarchy in business process models. To date, understanding hierarchy has been studied using the two-component framework for understanding hierarchy (Zugal et al., 2011, 2015). The two-component framework explains the effect of hierarchy using abstraction (benefits) and fragmentation (costs). This paper focuses on the abstraction component. Abstraction benefits usually stem from information hiding by hiding task-irrelevant information in (other) subprocesses and pattern recognition by highlighting well-known patterns through the use of subprocesses (Zugal et al., 2011, 2015). Our results indicate that both expert and novice model readers benefit from information hiding, with experts benefiting to a significantly higher degree than novices, and that experts particularly benefit from pattern recognition. Based on these results, this study further extends the abstraction component of the two-component framework by incorprating the expertise dimension (see Table 5). Furthermore, the implications of using hierarchy are discussed for practice. These implications include two design principles for introducing hierarchy. The first design principle implies that information should be structured in subprocesses so that information that is required to be perceived together for solving tasks or answering questions can be found in the same subprocess. A second principle can be used to optimize hierarchy by using a good layout within the subprocesses, so that experts can match patterns they can assess in their LTM easier with those highlighted in the subproceses. Furthermore, the potential for future research, including the possibility of an eye-tracking experiment, is discussed. This study also informs research in other areas, such as graph design and webpage design.

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