Measuring the Cognitive Complexity in the Comprehension of Modular Process Models

Michael Winter, Rüdiger Pryss, Thomas Probst, Julia Baß, and Manfred Reichert

***Abstract*—Modularization in process models is a method to cope with the inherent complexity in such models (e.g., model size reduction). Modularization is capable to increase the quality, the ease of reuse, and the scalability of process models. Prior conducted research studied the effects of modular process models to enhance their comprehension. However, the effects of modularization on cognitive factors during process model comprehension are less understood so far. Therefore, this paper presents the results of two exploratory studies (i.e., a survey research study with N = 95 participants; a follow-up eye tracking study with N = 19 participants), in which three types of modularization (i.e., horizontal, vertical, orthogonal) were applied to process models expressed in terms of the Business Process Model and Notation (BPMN) 2.0. Further, the effects of modularization on the cognitive load, the level of acceptability, and the performance in process model comprehension were investigated. In general, the results revealed that participants were confronted with challenges during the comprehension of modularized process models. Further, performance in the comprehension of modularized process models showed only a few significant differences, however, the results obtained regarding the cognitive load revealed that the complexity and concept of modularization in process models were misjudged initially. The insights unraveled that the attitude towards the application and the behavioral intention to apply modularization in process model is still not clear. In this context, horizontal modularization appeared to be the best comprehensible modularization approach leading to a more fine-grained comprehension of respective process models. The findings indicate that alterations in modular process models (e.g., change in the representation) are important to foster and enable their comprehension. Finally, based on our results, implications for research and practice as well as directions for future work are discussed in this paper.**

***Index Terms*—Process Model, Modularization, Cognitive Load Theory, Level of Acceptability, Survey, Study, Eye Tracking**

I. INTRODUCTION

The processes, procedures, and operations of organizations from different domains (e.g., industry [1], healthcare [2]) are usually documented in textual or graphical artifacts (i.e., process models). Regarding the latter, information in graphical process models are presented visually with a variety of symbols as an abstraction of the real world [3]. As a result, an abstract representation of the real world reduces the risk of cognitive deficiencies (e.g., limited capacity in the working memory) and, hence, fosters - inter alia - decision-making as well as communication of underlying information [4]. However, as a prerequisite for the aforementioned aspects, and in order to take advantage of process models, it must be ensured that such models are comprehended properly by all involved stakeholders [5].

Over the last decade, a lot of research was conducted to foster our general understanding of working with process models. Thereby, efforts were put into identifying the factors that have an effect on the comprehension of process models. In this context, a distinction is made between two comprehensive factors affecting the comprehension of such models: ① objective properties of a process model (e.g., size of a process model) must be considered separately from ② subjective character traits (e.g., process model expertise) of a model reader.

Regarding ① objective properties, [6] provides a comprehensive overview of forty studies that investigated the comprehension of process models. Further, the authors in [7] evaluated process model related factors and their effects on process model comprehension, whereas [8] studied the impact of notational deficiencies in a process model on model comprehension. Finally, the identification of an adequate trade-off between the size and the structure of process models was investigated in two studies presented in [9].

In the context of subjective character traits ②, the work in [7] evaluated the importance of various character traits on the comprehension of process models. In addition, the evaluated character traits from [7] and their effect on model comprehension were examined in a series of studies described in [10]. Moreover, the work in [11] presented the first analysis of cultural dependencies in decision-making in the context of process model comprehension.

In the recent past, there is an emerging trend in numerous domains considering an anthropocentric view, in which the study of the human cognition is taken into account [12]. Especially in the domains of science and technology, the study of aspects of human cognition (e.g., decision-making, problem solving) allow the definition of novel approaches in order to support and obtain an improved performance from individuals in their work tasks [13], [14]. Therefore, technology artifacts (e.g., software code) are considered in detail and their effects on aspects of human cognition (e.g., reading and comprehension) are evaluated in order to reveal the inherent complexity of such artifacts as well as how to positively reduce this complexity (i.e., cognitive complexity [15]). For this reason, in the context of process model comprehension,

Michael Winter, Julia Baß, and Manfred Reichert are with the Institute of Databases and Information Systems, Ulm University, Ulm, Germany; (e-mail: michael.winter@uni-ulm.de, julia.bass@uni-ulm.de, manfred.reichert@uni-ulm.de).

Rüdiger Pryss is with the Institute of Clinical Epidemiology and Biometry, University of Würzburg, Würzburg, Germany; (e-mail: ruediger.pryss@uni-wuerzburg.de).

Thomas Probst is with the Department for Psychotherapy and Biopsychosocial Health, Danube University Krems, Krems, Austria; (e-mail: thomas.probst@donau-uni.ac.at).

Corresponding Author: Michael Winter

more emphasis is put on subjective cognitive processes in respective research. For example, different cognitive strategies during process model comprehension were defined based on the results obtained from a large-scale study with over 1000 participants in [16]. Further, [17] researched various cognitive styles and their applied reading strategies in the comprehension of process models. Moreover, the works in [18] and [19] were using eye tracking technologies in order to get insights about cognitive aspects as well as processes and their effects on model comprehension.

Usually, process models from organizations in real-life projects contain a high information density and, hence, vary in respect to their size and complexity [20]. As a consequence, this results in additional difficulties for the human cognition (e.g., limited capacities in the working memory) regarding a proper and correct comprehension of these process models. However, an existing approach to tackle this issue and to relieve human cognition (e.g., reduction of the capacities in the working memory) is to apply a modularized structure in these models (i.e., modularization) [21]. In general, modularization describes the concept to decompose a monolithic structure into smaller independent modules [22]. In terms of process models, a large process model is modularized into several smaller modules (i.e., process models), which may be complete per se as well as independently manageable. Consequently, the smaller process model modules contain a lower information density and, hence, inherent complexity is reduced having a positive effect on human cognition. More specifically, the positive effects of modularization in process models are presented in a first review in [23]. In this work, it was shown that process models can be comprehended better in a modularized design due to the reduction of the process model size and complexity respectively. The results obtained in a study presented from the authors in [24] confirmed prior results related to modularized process models in general. Interestingly, the work [24] revealed that especially for business practitioners, it is advisable to present the process models in a non-modularized instead of a modularized representation. A reason may be that the presentation of smaller process models impairs the comprehension of process models.

In order to get a better understanding of the effects of modularized process models on the comprehension of respective models, a deeper investigation of the effects of modularization in process models on the human cognition is still missing so far. In more detail, further research is needed to investigate the cognitive effects of modularization on the comprehension of process models. Additionally, the behavioral intention and performance efficiency during the comprehension of modularized process models may unravel new insights that can foster their comprehension by the definition of supporting measures (e.g., comprehension guidelines). Generally, a vast body of research exists highlighting the benefits of modularization in process models regarding their comprehension (e.g., [25], [26], [27]). Thereby, the approach was pursued in previous research to compare the effects between modularized and non-modularized process models [28]. As another contribution in this context, the work at hand presents two exploratory studies that investigated the effects of three different modularization types (i.e., horizontal, vertical, orthogonal) on the comprehension of process models expressed in terms of the BPMN 2.0 from a cognitive point of view. Therefore, the following four research questions (RQ) were addressed in this work:

RQ 1: Does the use of different modularization types in process models have an effect on the cognitive load during the comprehension of BPMN 2.0 process models?

RQ 2: Does an explanation about modularization in process models have an effect on the cognitive load during the comprehension of BPMN 2.0 process models?

RQ 3: Does the use of different modularization types in process models have an effect on the level of acceptability during the comprehension of BPMN 2.0 process models?

RQ 4: Does the use of different modularization types in process models have an effect on the comprehension performance of BPMN 2.0 process models?

In order to address the defined RQs, two exploratory studies (i.e., Study I and Study II) were conducted. Thereby, Study I was conducted using a survey research design while Study II was conducted as a follow-up eye tracking study. Regarding the research questions, **RQ 1** was only addressed in Study I, whereas **RQ 4** was only addressed in Study II. **RQ 2** and **RQ 3**, however, were addressed in Studies I and II. In **RQ 1**, the cognitive load of participants who were confronted with three different modularization types (i.e., horizontal, vertical, orthogonal) during process model comprehension were assessed. Thereby, the cognitive load is composed of the dimensions intrinsic, extraneous, and germane cognitive load. In turn, **RQ 2** was concerned with the question whether an explanation about modularization effects the cognitive load and its related dimensions (i.e., pre- vs. post-explanation). In **RQ 3**, the level of acceptability during the comprehension of process models was evaluated. Therefore, the perceived usefulness for understandability (PUU), the perceived ease of understandability (PEU), the subjective ease of use (SEU), and the subjective comprehensibility (SC) were evaluated. Finally, in **RQ 4**, performance in process model comprehension (i.e., score, duration, number of fixations, average fixation duration) of participants with respect to the three different modularization types was measured in a study relying on eye tracking technology. Fig. 1 summarizes the addressed research questions in respective studies.

The structure of this paper is as follows: Section II provides theoretical background about modularization in process models. Materials and methods of the two conducted studies are described in Section III. In Section IV, obtained results of both studies are presented descriptively, tested for significance, and discussed. Moreover, Section IV provides limiting factors, implications for research as well as practice, and future work. Finally, Section V summarizes the paper.

II. THEORETICAL BACKGROUND

Modularization constitutes a crucial design methodology in the creation of complex technology [29]. The main principle of modularization characterizes the decomposition of a monolithic structure into smaller modules in order to foster

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

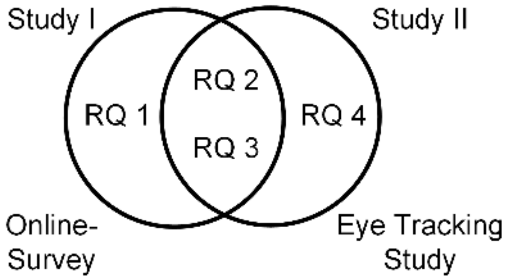


Fig. 1. Addressed Research Questions in Studies I and II

flexibility, reusability, and, primarily, to decrease complexity in technology systems [30]. Vice versa, the composition of smaller modules enables the creation of novel technology systems with an unprecedented inherent complexity (e.g., artificial intelligence) [31]. A module represents a detachable physical (e.g., car component) or non-physical (e.g., software code) construct as a hierarchical part of an entity (e.g., system) [32]. Thereby, modules are subject to clearly defined boundaries (i.e., non-functional requirements) regarding their functionality in an entity. Regarding the latter, modularity describes the characteristic of an entity, which components (i.e., modules) may be combined or separated during the design phase. The advantages of a modular structure in such a design are that these modules are independently manageable, interchangeable, and complete per se. For this reason, modularization is widespread and applied in various domains. For example, in robotic systems, a modular design allows for different morphologies in problem solving [33], whereas industrial design uses modularization for combining smaller subsystems to create larger systems [34]. Another prominent domain of application of modularization is in the context of process models [35], [36], [37]. More specifically, a process model or an aspect thereof (e.g., routine) is depicted into smaller process models. Therefore, it is frequently used in complex process models (e.g., reduction of model size) for the purpose of reuse and a better comprehension of such models [23]. In general, for the start of the exploration, three different modularization types (i.e., horizontal [38], vertical [24], orthogonal [39]) that have become established in the context of process models, are introduced in the following and, furthermore, were used in the reported two studies. Note that the work at hand considered only process models expressed in terms of the BPMN 2.0 and modularization was applied activity-based in all three modularization types (see Section III-B). Yet, different types of modularization exist and presented modularization approaches can also be applied in other process modeling notations (e.g., Event-driven Process Chains [25], UML Activity Diagram [40]) as well as functions (e.g., role-based) [41]. The following Fig. 2 presents the BPMN 2.0 modeling elements, which are used in the explanations.

- Activity: An activity is an atomic task and represents a step in a process.
- Subprocess: A subprocess is an abstracted process step, which consists of a number of related activities.
- Sequence flow: The sequence flow connect all modeling elements in a process model and defines the direction of the process flow.
- Event: An event indicates that something is happening in the process, which affects its process flow.

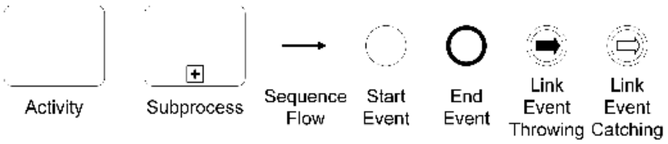


Fig. 2. BPMN 2.0 Modeling Elements

A. *Horizontal Modularization*

In the horizontal modularization type, a process model is divided into smaller independent, but not self-contained process models [41]. Thereby, process information are not abstracted and, hence, are presented fine-grained on one level (i.e., no hierarchy). Usually, the process flow is oriented along the defined paths on a horizontal level (i.e., left-to-right). This modularization type reduces the overall complexity of a process model and, hence, has a positive effect on process model comprehension. Furthermore, horizontal modularization increases reusability as well as maintainability of process models. In addition, the reusability of the decomposed process models may foster collaboration through a precise definition of affiliations. More particularly, through the use of additional concepts (i.e., pools, lanes) in the process models using horizontal modularization, the affiliations of the documented process may be specified more accurately. In BPMN 2.0 process models, horizontal modularization is realized with the application of specific event types (e.g., link, message events). For example, when using a link event, the process models are connected with links, whereas a link represents a one-way transfer to another link. In general, a link represents a similar functionality as a GoTo statement known from computer programming. An example of horizontal modularization in a BPMN process model is shown in Fig. 3 (a). After the execution of activity A, the process flow reaches the throwing link event with label 1. The link event refers to the related catching link event (i.e., also label 1) and, hence, the process flow continues horizontally in the other process model. Further modeling elements are executed according the same principle up to the end of the process model.

B. *Vertical Modularization*

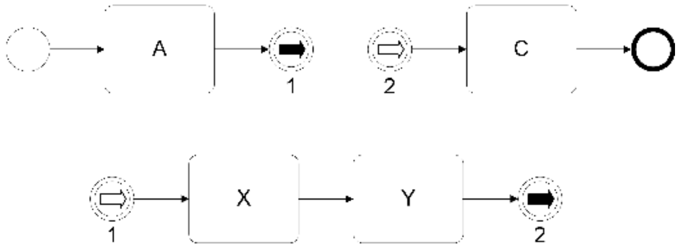
In contrast to horizontal modularization, the vertical modularization refers to the decomposition of a process model into refined subprocesses [42]. More specifically, the inherent high abstraction level in a process model is reduced and details of the process model are hidden in underlying subprocesses. More specifically, juxtaposed to horizontal modularization, process information are encapsulated and structured in a vertical hierarchy. On the top level of the hierarchy, the abstract process model is shown and with increasing hierarchy depth the activities are defined more precisely. In general,

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

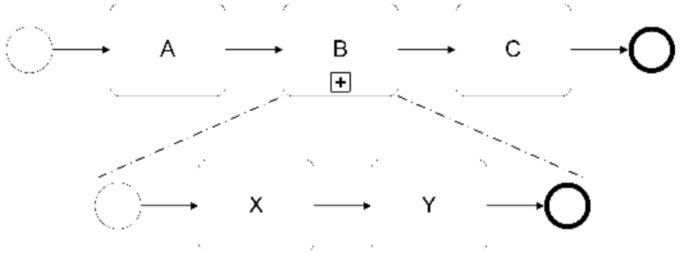
subprocesses are self-contained process models, but are dependent on the superordinate process model, thus limiting their reusability. However, a major benefit of using subprocesses is that the comprehensibility of especially complex and large process models can be increased [43]. Moreover, although the reusability is limited, subprocesses reduce redundancies in a process model and, thus, facilitate model maintainability. The realization of vertical modularization in BPMN 2.0 is made with collapsed or expanded subprocesses. The collapsed subprocess decomposes activities into more fine-grained and self-contained process models in a vertical downward direction, as known from hierarchical structures. In turn, an expanded subprocess describes the seamless integration of the subprocess in the sequence flow of the superordinate process model. Fig. 3 (b) illustrates a process model with an expanded subprocess. In this figure, the activity B represents a subprocesses that triggers the execution of activity X and Y. More specifically, activity B is the abstract high-level activity in the hierarchy, which represents vertically the activities X and Y. After the execution of both activities, the subprocesses is completed and the process execution continues along the sequence flow.

C. Orthogonal Modularization

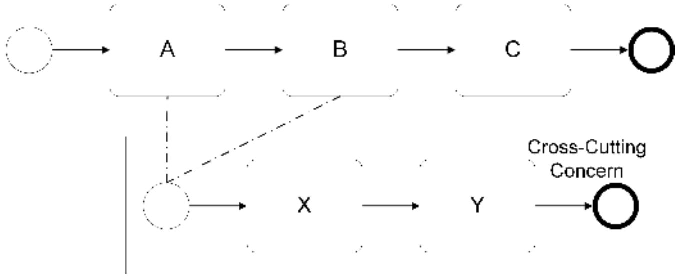
The orthogonal modularization is based on the aspect-oriented programming paradigm in order to increase modularity in a process model. In this modularization type, the decomposed process model is separately specified with a pointcut (i.e., join point) [44]. Generally, orthogonal modularization is mainly used for the decomposition of cross-cutting concerns, such as privacy or security aspects (e.g., password inquiry) [41]. Thereby, similar to the other two modularization types, the size of a process model is reduced having a positive effect on process model comprehension. Furthermore, orthogonal modularization increases the maintainability as well as reusability through the clear separation of cross-cutting concerns. Orthogonal modularization in BPMN 2.0 process models is realized in two ways. One way describes the extrapolation of cross-cutting concerns within a process in an event subprocess, similar to horizontal and vertical modularization. Therefore, specified exception events that could be triggered at any point in time (e.g., caused by an external event) refer (e.g., via link event) to the defined event subprocess. The other way, in turn, is oriented by the adoption of specific notions (i.e., advice, join point, point cut) known from aspect-oriented programming [45]. In particular, repeating cross-cutting concerns (e.g., key generation for login) within a process model are outsourced and depicted in a separate modularized process model [46]. Further, a notion (e.g., security aspect) is provided for the outsourced model defining its function. Regarding the latter, Fig. 3 (c) depicts a process model with orthogonal modularization. More specifically, before the execution of activity A and B, process flow triggers the execution of the cross-cutting concern once for activity A and B. Thereby, the cross-cutting concern represents the outsourced process model and, hence, can only be used for the defined function.



(a) Horizontal Modularization



(b) Vertical Modularization



(c) Orthogonal Modularization

Fig. 3. Modularization Types in BPMN 2.0

III. METHODS AND MATERIALS

A. Participants

In Study I, which addressed **RQ 1** and, as did Study II, **RQ 2** and **RQ 3**, a total of 95 students participated. The participants were enrolled from an entry course in the context of Business Process Management at Ulm University. 45 participants were female, 48 male, and 2 others. 52 participants were younger than 25 and the rest indicated an age between 25 and 35. Based on information obtained from a demographic questionnaire, 63 participants stated that they already had experience in process modeling as well as process model comprehension. The participants were randomly divided into three groups (i.e., horizontal, vertical, orthogonal). For the random allocation of the participants, the randomization function of Google Forms was used (see Study Design). The group with the horizontal modularization type consisted of 35 participants, the group with vertical modularization of 28 and, finally, the orthogonal group of 32 participants. Table I presents the baseline comparisons between the three modularization groups (i.e., horizontal, vertical, orthogonal).

In Study II, which addressed **RQ 4** and, as did Study I, **RQ 2** and **RQ 3**, 19 participants were invited for the study and all participants were male. 4 participants indicated an age younger than 25 and the others had an age between 25 and 35. Three participants had no experience in the context of process mod-

TABLE I
SAMPLE DESCRIPTION AND COMPARISON OF STUDY I IN BASELINE VARIABLES

Variable	Horizontal (N = 35)	Vertical (N = 28)	Orthogonal (N = 32)	p value
Gender N (%)				
female	15 (42.86)	13 (46.43)	17 (53.12)	
male	18 (51.43)	15 (53.57)	15 (46.88)	
other	2 (5.71)	0 (0.00)	0 (0.00)	p = .615[a]
Age N (%)				
$<$ 25 years	18 (51.43)	19 (67.86)	16 (50.00)	
25 - 35 years	17 (48.57)	9 (32.14)	16 (50.00)	p = .327[a]
Experience N (%)				
yes	25 (71.43)	21 (75.00)	17 (53.13)	
no	10 (28.57)	7 (25.00)	15 (46.87)	p = .149[a]

[a] Fisher's exact test

eling and comprehension of process models. Furthermore, no allocation of the participants into modularization groups was necessary, since all participants followed the same procedure in Study II (see Section III-D).

B. Materials

Two studies (i.e., Study I and Study II) were conducted. Thereby, Study I consisted of three parts and the following process models were used: For Part One (see Section III-D), 12 different process models expressed in terms of the BPMN 2.0 were used [47]. The choice to use BPMN 2.0 process models was made for several reasons. BPMN 2.0 is the de facto industry standard for the creation of readily comprehensible process models and an ISO/IEC 1950:2013 standard [48]. In particularly, BPMN 2.0 serves as a seamless link between process design (e.g., process documentation) and implementation (i.e., process automation). Moreover, during the last decade, a vast body of knowledge evolved, which has promoted the widespread application of BPMN 2.0 in practice as well as in research [49]. For each modularization type (i.e., horizontal, vertical, orthogonal), four process models needed to be comprehended by the participants. Further, modularization was applied in the process models activity-based. More specifically, process models were depicted into smaller models based on semantically related activities (see Section IV-G). Thereby, the four process models documented the following process scenarios: order, refuel, delivery service, and, finally, credit application. In this context, the modularized process models had intentionally a low complexity in terms of model size and structure in order to avoid potential side effects (e.g., cognitive overload due to model size [50]), which could have an effect on the outcome of interest (see Section IV-E). In particularly, the process models were composed of basic elements of BPMN 2.0 and contained an average number of 40 modeling elements. In Part Two of Study I, a BPMN 2.0 process model, presented in the respective modularization type, was shown to the participants, with which the respective modularization types were described and the application of modularization in this context was explained. This process model described a loan process and was created by the authors in [41]. Regarding the latter, this work provides a validated conceptual basis for the reduction of complexity in process models through the accumulation of defined patterns. Thereby, the presented loan process in this work is kept simple but consists of the most common modeling elements of BPMN 2.0 [51]. Hence, the loan process reflected a good balance of simplicity as well as complexity and was, therefore, adequate for the use in this study. In the final Part Three of Study I, a similar loan process from [41] was used in all three modularization types[1]. Finally, considered performance measures in Study I are described in Section III-C and used instrumentation in Section III-E.

In Study II, which consisted of three parts, the following process models were used: 81 different BPMN 2.0 process models with similar model properties as the models used in Study I documenting 9 process scenarios were used in Part Two. Particularly, for each modularization type, 27 process models were created. Thereby, the process models documented the following process scenarios: powershell, online shopping, pizza baking, refuel, order, shipping, smartphone unlock, loan, and, finally, credit card payment. Similar as in Study I, the process models (i.e., average number of modeling elements was 25) were kept simple intentionally in order to ensure that the emphasis can be put on the concept of modularization. Furthermore, for each process model, four true-or-false comprehension questions needed to be answered by the participants. The comprehension questions referred on process model syntactics as well as semantics[2]. Finally, considered performance measures in Study II are described in Section III-C and used instrumentation in Section III-E.

C. Performance Measures

In the following, the considered performance measures, which have been used in both studies, are described in detail[3].

Study I & Study II:

- Cognitive load: The cognitive load depicts the invested cognitive capacity of the working memory during a task. Thereby, the cognitive load consists of the following dimensions: intrinsic, extraneous, and germane cognitive load [52]. Thereby, intrinsic load constitutes the complexity of intrinsic information and is affected by existing

---

[1] The materials used in Study I are available at: https://drive.google.com/open?id=1rytYcYS5oZ8HVpWhF0Fdb2sZ9USxVnyW

[2] The materials used in Study II are available at: https://drive.google.com/open?id=1XYCbq3Ai8gd-xy7maGTx8nt-YfyEFc7R

[3] The questions regarding cognitive load and level of acceptability are available at: https://drive.google.com/file/d/1q3FmujGhwGkNM8a-oo3QJsNgFDaCaAtW/view?usp=sharing

knowledge and element interactivity (e.g., demand on the working memory). In turn, extraneous load is affected by the way information is presented. Finally, germane load describes the mental effort to process and comprehend information based on constructed mental models [53]. To measure the single dimensions related to the cognitive load, the adapted measurement proposed in [54] was used in Studies I and II in order to investigate **RQ 1** (i.e., Study I) and **RQ 2** (i.e, Studies I and II). Thereby, respective work demonstrated that the application of the proposed measurement is a validated and reliable instrument for measuring the cognitive load. Hence, the measurement can be applied from an informed (i.e., with prior knowledge) and naïve point of view (i.e., without prior knowledge) about the concept of cognitive load. The single dimensions, which were comprised of several items (i.e., two for intrinsic, three for extraneous, and germane cognitive load), had to be rated on a 7-point Likert scale from strongly disagree (i.e., 1) to strongly agree (i.e., 7).

- Perceived usefulness for understandability (PUU): Derived from the technology acceptance model (TAM) [55], PUU describes the perceived usefulness of a particular modularization type within a process model in the context of process model comprehension (**RQ 3**). Therefore, four items on a 7-point Likert scale from strongly disagree (i.e., 1) to strongly agree (i.e., 7) needed to be answered totaling to a min/max value of (4 x 7). Moreover, the used measure was evaluated for validity and reliability in prior research [56].
- Perceived ease of understandability (PEU): Derived from TAM, PEU characterizes that the use of a particular modularization type within a process model is associated with less mental effort (**RQ 3**). Therefore, four items on a 7-point Likert scale from strongly disagree (i.e., 1) to strongly agree (i.e., 7) needed to be answered totaling to a min/max value of (4 x 7). Moreover, the used measure was evaluated for validity and reliability in prior research [56].

The following performance measures were only used in Study I with respect to **RQ 3**

- Subjective ease of use (SEU): Derived from PEU, in SEU, Participants needed to indicate a modularization type regarding the ease of use. Therefore, based on subjective preferences, all three modularization types were juxtaposed and the participants chose a modularization type with the highest intention to use. Accordingly, the frequency of the respective modularization types was evaluated.
- Subjective comprehensibility (SC): The most comprehensible modularization type was inquired from the participants. Similar as SEU, all three modularization types were juxtaposed and the participants were asked to indicate the best comprehensible modularization type based on subjective preferences. Accordingly, the frequency of the respective modularization types was evaluated.

Finally, the following performance measures were only used in Study II with respect to **RQ 4**. Thereby, prior research demonstrated that considered performance factors were suitable in order to evaluate the comprehension of process models [57]. Furthermore, various parameters can be considered in the analyses of eye tracking data in the context of process model comprehension [19]. However, similar research (e.g., [18], [16] demonstrated that the considered eye tracking measures were suitable for a first evaluation of the process model comprehension performance in modularized models:

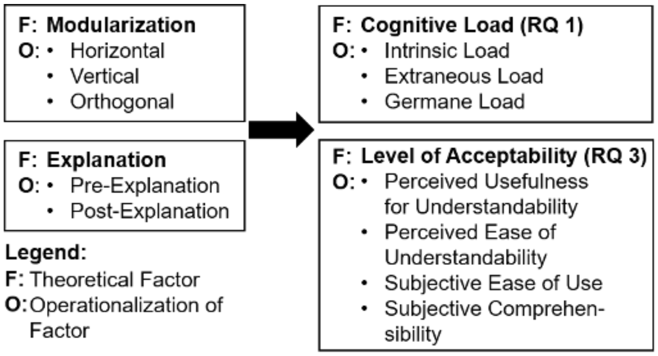
- Score: Participants needed to answer for each comprehended process model four true-or-false comprehension questions. The comprehension questions referred to the semantic as well as syntactic dimensions of the process models. For each correct given answer, a point was awarded. Particularly, a participant could score a maximum of four points per process model.
- Duration: A timestamp was added at the moment participants started comprehending respective process models. After comprehending a process model and answering respective comprehension questions, another timestamp was added. This allowed us to measure the duration needed for comprehension on a fine-grained level.
- Fixation: Fixations constitute eye movements of very low velocity at a specific point in a stimulus (e.g., image), in which relevant information is extracted about what is being looked at [58]. The measuring of the number of fixations allowed us to make conclusion about the cognitive load as well as about specific points (e.g., process modeling constructs) in the stimulus (i.e., process model) that may pose a challenge in the comprehension process for the participants.
- Fixation duration: The fixation duration indicates the period of time in which the eyes remain still while looking at a stimulus [59]. During this period of time, the acquisition of information from the currently viewed point in a stimulus (i.e., process model) takes place. Hence, the analysis of the average fixation duration allowed for additional assumption regarding the cognitive load during the comprehension of process models [60].

Based on the defined measures, Fig. 4 summarizes the research models for Study I (a) and Study II (b). More specifically, both research models investigate whether the cognitive load, level of acceptability, and performance in process model comprehension is affected by the three modularization types applied in the process models. In addition, for Study I (see Fig. 4 (a)), the provision of an explanation about modularized process models on respective measures was explored.

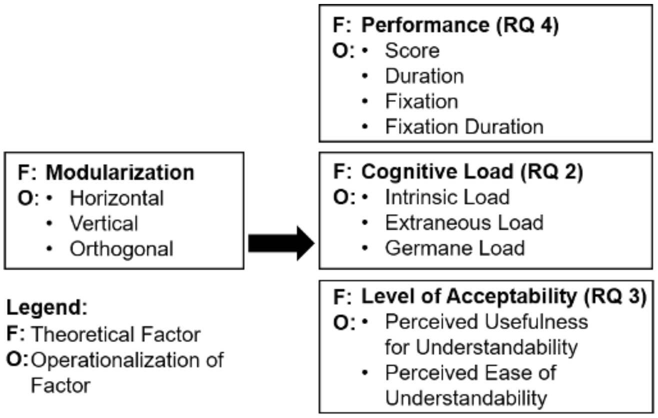
D. Study Design

The study design is based for both studies accordingly on the guidelines proposed in [61], which provided all essentials for studies in computer science.

Study I was an online-based survey (i.e., survey research design). As an exploratory study, a survey constituted a suitable methodology for the acquisition of first data regarding the perception and acceptance of modularization in process models. Moreover, the possibility of conducting the survey online (i.e., participants were neither spatially bound, nor bound



(a) Research Model - Study I



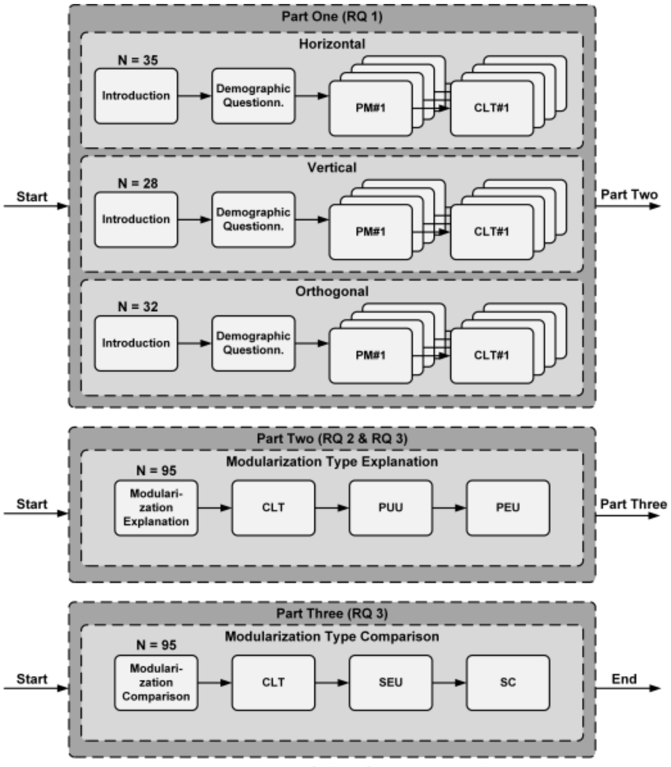
(b) Research Model - Study II

Fig. 4. Research Models for Studies I and II

by time) allowed us to increase the scope of your study and to collect a large number of data in a short time. Finally, obtained data can be examined in more detail in further studies (see Section IV-G). As prerequisite for participation in Study I, a mobile device (i.e., laptop, smartphone) was required (see Section IV-E). Further, Study I was conducted at Ulm University in an entry course on Business Process Management. Hence, all participants of this study were recruited in this course. Moreover, as an incentive for a conscientious participation, a bonus point for the later exam of this course was awarded for all participants, who participated in the study. Before the study reported in this paper, two pilot studies with four participants each were conducted. The pilot studies were used in order to obviate ambiguities as well as misunderstandings. Furthermore, the overall quality of the study material was increased and technical functions (i.e., data collection) had been checked for their proper implementation. In the course, a web link leading to the online survey was provided to the participants via a projector. Thereby, the procedure of Study I, which consisted of three parts, was as follows: For Part One, participants were led to the survey page (i.e., Google Forms) by accessing the provided web link [62]. At accessing the web link, a randomization function, provided by Google Forms, was used to randomly allocate the participants into one of three groups (i.e., horizontal, vertical, orthogonal). Then, an introduction was presented to the participants, outlining the procedure and the goal of the study. Afterwards, participants were asked to answer a set of demographic questions (e.g., age, gender, expertise in process modeling). After completing this step, the participants needed to evaluate their assigned modularization type. More specifically, four modularized process models were presented in a successive order (see Section III-B). For each process model, participants had to answer a set of questions related to the three dimensions of the cognitive load (i.e., intrinsic, extraneous, germane) in order to investigate **RQ 1**. Afterwards, in Part Two, the allocated modularization type was exemplified, textual as well as graphical, explaining the application of modularization in process models to all participants. Moreover, an additional set of questions capturing the cognitive load was presented to address **RQ 2** (i.e., pre- vs. post-explanation). Then, the items concerning the perceived usefulness for understandability (PUU) and the perceived ease of understandability (PEU) were presented to the participants with respect to **RQ 3**. Finally, in Part Three and to further address **RQ 3**, all three modularization types were shown and participants were asked to compare and rank the three modularization types with regard to subjective usefulness (SEU) and comprehensibility (SC). Additionally, another questionnaire related to the cognitive load had to be answered. Finally, participants were able to leave feedback and the study was finished. The complete execution of Study I took about 20 minutes. Fig. 5 illustrates the design used in Study I. In more detail, in Part One, **RQ 1** (i.e., cognitive load) was addressed. In Part Two, **RQ 2** (i.e., pre- vs. post-explanation) and **RQ 3** (i.e., level of acceptability; PUU and PEU) were investigated. Finally, in Part Three, **RQ 3** (i.e., level of acceptability; SEU and SC) was addressed.

Study II was conducted as a follow-up eye tracking study. The eye tracking study enabled us to gain first insights into performance metrics (e.g., duration, number of fixations) during the comprehension of process models with varying modularization approaches. Moreover, obtained performance metrics can be juxtaposed with related cognitive load whether there might be a correlation between performance metrics, cognitive load, and the comprehension of process models resulting in a correlated elevation respective measures with increasingly complex process models. In Study II, no participants were invited which already participated in Study I. The study was conducted at Ulm University in a designated eye tracking lab. Prior to this study, two pilot studies with four participants each were conducted for the purpose of reviewing the used study material. Due to the device limitation, only one participant could be evaluated each time and a session in Study II, which consisted of three parts, was as follows: In Part One, the study started with welcoming the participants and explaining the study procedure as well as a brief oral explanation about modularization in process models. Afterwards, similar to Study I, the participants were asked to answer a demographic questionnaire. Then, the participants were placed in front of the eye tracking device and the device was calibrated accordingly. Following this, the participants completed a brief tutorial in order to familiarize them with the functionality of the eye tracking device. After completing these mandatory steps, in Part Two, the participants were confronted with 9 modularized process models. In more detail, for each

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems



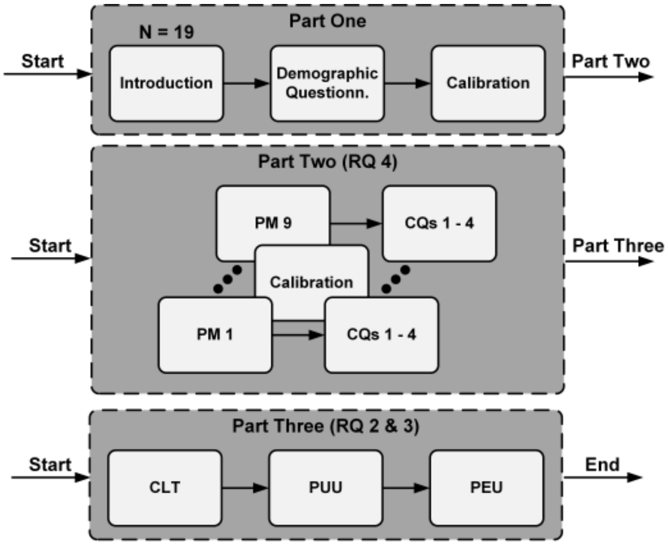
Legend: PM = Process Model; CLT = Cognitive Load Theory; PUU = Peceived Usefullness for Understandability; PEU = Perceived Ease of Understanding; SEU = Subjective Ease of Use; SC = Subjective Comprehensibility

Fig. 5. Study Design used in Study I

modularization type (i.e., horizontal, vertical, orthogonal) three process models were shown. Hence, obtained from the pool of the 81 process models (27 process models for each modularization type; see Materials), 3 x 3 process models were randomly shown to the participants. Furthermore, for each process model, the participants needed to answer four true-or-false comprehension questions. After three evaluated process models, the eye tracking device was calibrated anew in order to prevent faulty data. In this way, the performance measures regarding the comprehension performance of modularized process models were assessed with respect to **RQ 4**. After all process models had been evaluated, in Part Three, the participants needed to answer a questionnaire capturing the cognitive load (**RQ 2**), perceived usefulness for understandability (PUU), and perceived ease of understandability (PEU) (**RQ 3**). Finally, after the opportunity to leave feedback, the study ended. The time required for the execution of the study was approximately 30 minutes. The used design in Study II is shown in Fig. 6. More specifically, in Part Two, **RQ 4** (i.e., process model comprehension performance) was investigated. In Part Three, **RQ 2** (i.e., cognitive load) and **RQ 3** (i.e., level of acceptability; PUU and PEU) were addressed.

E. Instrumentation

In general, all materials used in Study I were provided in Google Forms. More specifically, demographic data (e.g., age, gender, experience in process modeling), information related to the cognitive load and the level of acceptability were collected with questionnaires in Google Forms.



Legend: PM = Process Model; CQ = Comprehension Question; CLT = Cognitive Load Theory; PUU = Perceived Usefulness for Understandability; PEU = Perceived Ease of Understanding

Fig. 6. Study Design used in Study II

In Study II, demographic data, questions concerning the cognitive load and level of acceptability were collected with paper-based questionnaires. Eye movements were captured with SMI iView X Hi-Speed system. Therefore, the eye tracking device was placed in front of a 23” monitor (resolution of 1920x1080, 96 PPI) presenting the respective process models to the participants. Moreover, to ensure a high data-quality, a 13-point calibration was performed. Eye movements were recorded at a sampling rate of 240 Hz. For answering the true-or-false comprehension questions, participants used a keyboard with two predefined keys providing the respective answering options (i.e., ’true’ and ’false’). Eye tracking data collected during Study II was analyzed and visualized with SMI BeGaze 3.7.59 software. Finally, SPSS 25 was used for all statistical analyses.

IV. RESULTS

This section presents the descriptive as well as inferential statistics of the results obtained from Studies I and II.

A. Results of Study I

Table II presents for each process model (i.e., four in total) mean (M) and standard deviation (SD) regarding the respective dimension (i.e., intrinsic, extraneous, germane) of the cognitive load obtained of Part One from Study I. In general, the dimensions intrinsic and extraneous load are on a moderate level but the results fluctuate differently for each process model. However, germane cognitive load reflects an increased level in all three modularization types. Table III shows mean (M) and standard deviation (SD) for the cognitive load as well as the level of acceptability obtained in Part Two from Study I. In detail, the table shows the value for the three dimensions after the participants were provided with an explanation about modularization. Furthermore, perceived usefulness for understandability (PUU) as well as perceived ease of understandability (PEU) reflecting the level of acceptability of respective modularization type are shown in Table III. Regarding the cognitive load, the three dimensions show increased values juxtaposed to the results presented in Table II. Concerning PUU and PEU, it appears that the participants were indecisive regarding the benefits of modularization in process models (i.e., average 16 out of 28 for PUU and PEU).

TABLE II
DESCRIPTIVE RESULTS FOR COGNITIVE LOAD OF PART ONE FROM STUDY I

Variable	Horizontal	Vertical	Orthogonal
ICL PM 1	1.83 (.82)	2.20 (.90)	1.80 (.81)
ICL PM 2	2.40 (.92)	2.79 (1.24)	2.31 (1.15)
ICL PM 3	3.83 (1.21)	4.57 (1.37)	3.72 (1.22)
ICL PM 4	3.23 (1.20)	3.98 (1.34)	3.33 (1.21)
ECL PM 1	1.99 (.85)	2.17 (.83)	1.94 (.96)
ECL PM 2	2.35 (1.33)	2.61 (1.44)	2.81 (1.36)
ECL PM 3	3.59 (1.35)	4.07 (1.53)	3.75 (1.22)
ECL PM 4	2.86 (1.23)	3.49 (1.48)	3.23 (1.23)
GCL PM 1	4.12 (1.24)	4.69 (1.16)	4.38 (.92)
GCL PM 2	4.30 (1.36)	4.67 (1.30)	4.34 (.99)
GCL PM 3	4.52 (1.05)	5.02 (1.03)	4.56 (1.07)
GCL PM 4	4.39 (1.20)	4.88 (1.02)	4.67 (.95)

Note: ICL = Intrinsic Cognitive Load; ECL = Extraneous Cognitive Load; GCL = Germane Cognitive Load; PM = Process Model

TABLE III
DESCRIPTIVE RESULTS FOR COGNITIVE LOAD AND LEVEL OF ACCEPTABILITY OF PART TWO FROM STUDY I

Variable	Horizontal	Vertical	Orthogonal
ICL	3.70 (1.23)	4.00 (1.29)	3.50 (1.18)
ECL	2.97 (1.02)	3.56 (1.34)	2.95 (1.14)
GCL	4.59 (1.05)	4.87 (1.02)	4.83 (.95)
PUU 1	2.69 (1.23)	3.46 (1.43)	2.78 (1.43)
PUU 2	4.74 (1.34)	4.71 (1.24)	4.50 (1.41)
PUU 3	2.83 (1.10)	3.39 (1.50)	3.03 (1.40)
PUU 4	5.03 (1.36)	5.04 (1.20)	4.91 (1.25)
PUU Sum	15.29 (2.35)	16.61 (2.47)	15.22 (2.61)
PEU 1	4.77 (1.52)	4.86 (1.33)	4.69 (1.23)
PEU 2	2.46 (1.22)	2.96 (1.50)	2.59 (1.29)
PEU 3	4.77 (1.24)	4.50 (1.35)	4.84 (1.30)
PEU 4	2.83 (1.18)	3.07 (1.36)	3.03 (1.23)
PEU Sum	14.83 (2.73)	15.39 (3.08)	15.16 (2.36)

Note: ICL = Intrinsic Cognitive Load; ECL = Extraneous Cognitive Load; GCL = Germane Cognitive Load; PUU = Perceived Usefulness for Understandability; PEU = Perceived Ease of Understandability

Finally, the results (i.e., frequencies and percentages) for subjective ease of use (SEU) and subjective comprehensibility (SC) (i.e., subjective level of acceptability) as well as mean (M) and standard deviation (SD) for the cognitive load of Part Three from Study I are shown in Table IV. Regarding SEU, participants indicated that a horizontal modularization reflects a higher subjective ease of use compared to a vertical and orthogonal modularization. Furthermore, the results related to SC were in compliance with the results related to SEU showing that a horizontal modularization was better comprehensible juxtaposed to a vertical and orthogonal modularization. Regarding the cognitive load, the three dimensions are in line with the results about the cognitive load obtained in Part Two (see Table III and represent higher values in general in comparison to the results of obtained in Part One from Study I (see Table II).

TABLE IV
DESCRIPTIVE RESULTS FOR LEVEL OF ACCEPTABILITY AND COGNITIVE LOAD OF PART THREE FROM STUDY I

Variable	Horizontal	Vertical	Orthogonal
SEU N (%)			
Horizontal	26 (74.29)	14 (50.00)	14 (43.75)
Vertical	7 (20.00)	14 (50.00)	10 (31.25)
Orthogonal	2 (5.71)	0 (0.00)	8 (25.00)
SC N (%)			
Horizontal	26 (74.29)	14 (50.00)	17 (53.13)
Vertical	6 (17.14)	13 46.43)	10 (31.25)
Orthogonal	3 (8.57)	1 (3.57)	5 (15.62)
CLT	ICL	ECL	GCL
	4.95 (1.56)	4.42 (1.57)	4.92 (.99)

Note: SEU = Subjective Ease of Use; SC = Subjective Comprehensibility; CLT = Cognitive Load Theory; ICL = Intrinsic Cognitive Load; ECL = Extraneous Cognitive Load; GCL = Germane Cognitive Load

B. Results of Study II

Table V presents mean (M) and standard deviation (SD) of the performance results score, duration (s), fixation, and average fixation duration (ms) of Study II obtained for each modularization type. Regarding the score, there were only minimal differences and participants nearly reached the maximum score (i.e., max is 4) on average in answering the comprehension questions. However, between duration and fixation, there were differences between the three modularization types (i.e., horizontal, vertical, orthogonal). In detail, for horizontal modularization, participants needed more time and more fixations during process model comprehension. However, in vertical modularization, participants were the fastest and required fewer fixations. Finally, regarding the average fixation duration, while there were only minimal differences in the average fixation duration between vertical and orthogonal modularization, however, it appears that the horizontal modularization indicated longer average fixation durations.

Finally, results representing PUU and PEU (i.e., level of acceptability) as well as the three cognitive load dimension (i.e., intrinsic, extraneous, germane) of Part Three from Study II are shown in Table VI. Regarding PUU and PEU, results were on a moderate level but, in comparison with PUU and PEU from Study I (see Table III), they showed lower values. Moreover, the specific cognitive load dimensions were on a moderate level, whereas extraneous cognitive load shows an increased value juxtaposed to intrinsic and germane cognitive load. In addition, compared to the results regarding the cognitive load of Part Two and Three from Study I (see Table III and IV), the results are showing lower values.

C. Inferential Statistics

1) Results for RQ 1: To evaluate whether the differences seen in the descriptive results with respect to **RQ 1** reach statistical significance, analyses of variances (ANOVAs) were

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

TABLE V
DESCRIPTIVE RESULTS FOR THE PERFORMANCE RESULTS OF PART TWO FROM STUDY II

Variable	Horizontal	Vertical	Orthogonal
Score			
PM 1	3.47 (.77)	3.63 (.60)	3.42 (1.07)
PM 2	3.42 (.77)	3.63 (.76)	3.68 (.67)
PM 3	3.37 (.90)	3.63 (.50)	3.53 (.70)
Duration			
PM 1	71.61 (30.44)	64.73 (33.15)	67.06 (15.95)
PM 2	82.73 (37.09)	67.46 (24.70)	76.15 (31.44)
PM 3	83.18 (28.84)	65.74 (20.69)	71.27 (25.05)
Fixation			
PM 1	60.84 (27.11)	55.82 (21.15)	56.14 (14.58)
PM 2	76.78 (35.06)	58.82 (19.04)	64.03 (26.38)
PM 3	72.92 (27.54)	55.72 (17.93)	61.57 (19.38
Fix. Dur.			
PM 1	238.32 (34.12)	224.85 (29.38)	242.89 (41.60)
PM 2	214.80 (29.30)	220.66 (33.29)	221.52 (27.84)
PM 3	258.54 (41.68)	208.32 (30.94)	201.73 (30.41)

Note: PM = Process Model

TABLE VI
DESCRIPTIVE RESULTS FOR LEVEL OF ACCEPTABILITY AND COGNITIVE LOAD OF PART THREE FROM STUDY II

Variable	Value	Variable	Value
PUU 1	2.11 (1.52)	PEU 1	4.79 (.86)
PUU 2	4.00 (1.00)	PEU 2	2.11 (1.20)
PUU 3	2.16 (1.26)	PEU 3	4.63 (.83)
PUU 4	4.00 (1.16)	PEU 4	2.05 (1.22)
PUU Sum	12.26 (1.97)	PEU Sum	13.58 (1.95)
CLT	ICL	ECL	GCL
	2.97 (1.17)	3.86 (1.01)	2.58 (.99)

Note: PUU = Perceived Usefulness for Understandability; PEU = Perceived Ease of Understandability; CLT = Cognitive Load Theory; ICL = Intrinsic Cognitive Load; ECL = Extraneous Cognitive Load; GCL = Germane Cognitive Load

TABLE VII
INFERENTIAL STATISTICS FOR RQ 1

	Intrinsic Cognitive Load		
ME 1	F(2.81; 258.25)	= 131.09	$p < .001$
ME 2	F(2.00; 92.00)	= 4.24	p = .017
IE	F(2.81; 258.25)	= .74	p = .608

	Extraneous Cognitive Load		
ME 1	F(2.90; 266.66)	= 53.34	$p < .001$
ME 2	F(2.00; 92.00)	= 1.52	p = .223
IE	F(5.80; 266.66)	= .78	p = .580

	Germane Cognitive Load		
ME 1	F(2.75; 252.78)	= 4.47	p = .006
ME 2	F(2.00; 92.00)	= 2.06	p = .133
IE	F(5.50; 252.78)	= .39	p = .875

Note: ME = Main Effect; IE = Interaction Effect

performed for all three cognitive load dimensions (i.e., intrinsic, extraneous, germane). Moreover, Greenhouse-Geisser correction was applied if necessary (i.e., significant Mauchly's sphericity test). Thereby, one within-subject factor ”model” (four levels: cognitive load dimension for process model 1 - 4) and one between-subject factor ”modularization” (three levels: horizontal, vertical, orthogonal) were examined. The main effect for the cognitive load dimensions for process model 1 - 4 (ME 1) and for the modularization comparison (ME 2) were evaluated as well as the interaction effect process model*modularization (IE). In addition, in the event of significance for ME 1, repeated contrasts were employed. Moreover, in the event of significance for ME 2, Post hoc analyses using the Bonferroni post hoc criterion were employed. Finally, all statistical tests were performed two-tailed and the significance value was set to $p < .05$. Table VII presents the results with respect to **RQ 1**.

Regarding intrinsic cognitive load, ME 1 was significant and repeated contrasts showed that the second process model (M = 2.48 (1.11)) had a higher intrinsic cognitive load ($p < .001$) than the first process model (M = 1.93 (.85)) and the third process model (M = 4.01 (1.30)) had a higher intrinsic cognitive load ($p < .001$) than the second process model but the fourth process model (M = 3.48 (1.27)) had a lower intrinsic cognitive load ($p < .001$) than the third process model. Furthermore, ME 2 was significant and Post hoc analysis using the Bonferroni post hoc criterion for significance indicated that the means of vertical modularization (M = 3.39 (1.21)) differed significantly from horizontal (M = 2.83 (1.03); p = .017) and orthogonal (M = 2.79 (1.10); p = .038) modularization.

Regarding extraneous cognitive load, ME 1 was significant and repeated contrasts showed that the second process model (M = 2.58 (1.37)) had a higher extraneous cognitive load ($p < .001$) than the first process model (M = 2.02 (.88)) and the third process model (M = 3.79 (1.37)) had a higher extraneous cognitive load ($p < .001$) than the second process model but the fourth process model (M = 3.17 (1.32)) had a lower extraneous cognitive load ($p < .001$) than the third process model.

Regarding germane cognitive load, ME 1 was significant and repeated contrasts showed that the second process model (M = 4.42 (1.22)) did not have a higher germane cognitive load (p = .676) than the first process model (M = 4.38 (1.13)) but the third process model (M = 4.68 (1.06)) had a higher germane cognitive load (p = .014) than the second process model but the fourth process model (M = 4.63 (1.08)) did not have a higher germane cognitive load (p = .528) than the third process model.

2) Results for RQ 2: To evaluate whether the differences seen in the descriptive results with respect to **RQ 2** reach statistical significance, analyses of variances (ANOVAs) were performed for all three cognitive load dimensions (i.e., intrinsic, extraneous, germane). Moreover, Greenhouse-Geisser correction was applied if necessary (i.e., significant Mauchly's sphericity test). Thereby, one within-subject factor ”explanation” (two levels: cognitive load dimension before as well as after providing an explanation about modularization in process models (i.e., pre- vs. post-explanation) and one between-subject factor ”modularization” (three levels: horizontal, vertical, orthogonal) were examined. The main effect for the explanation (ME 1) and for the modularization (ME 2) were evaluated as well as the interaction effect explanation*modularization (IE). In addition, in the event of significance for ME 2, Post hoc analyses using the Bonferroni post hoc criterion were employed. Finally, all statistical tests were performed two-tailed and the significance value was set to p

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

$< .05$. Table VIII presents the results with respect to **RQ 2**.

TABLE VIII
INFERENTIAL STATISTICS FOR RQ 2

	Intrinsic Cognitive Load		
ME 1	F(1.00; 92.00)	= 33.96	p < .001
ME 2	F(2.00; 92.00)	= 3.17	p = .047
IE	F(2.00; 92.00)	= .38	p = .688
	Extraneous Cognitive Load		
ME 1	F(1.00; 92.00)	= 5.87	p = .017
ME 2	F(2.00; 92.00)	= 2.44	p = .093
IE	F(2.00; 92.00)	= 1.54	p = .221
	Germane Cognitive Load		
ME 1	F(1.00; 92.00)	= 5.14	p = .026
ME 2	F(2.00; 92.00)	= 1.54	p = .221
IE	F(2.00; 92.00)	= .76	p = .471

Note: ME = Main Effect; IE = Interaction Effect

Regarding intrinsic cognitive load, ME 1 was significant and intrinsic cognitive load was higher (M = 3.72 (1.23)) after explanation than before (M = 2.98 (.91)). ME 2 was significant but Post hoc analysis using the Bonferroni post hoc criterion for significance indicated no significant differences due the lack of statistical power (i.e., weakly significant global effect (p = .047)).

Regarding extraneous cognitive load, ME 1 was significant and extraneous cognitive load was higher (M = 3.14 (1.18)) after explanation than before (M = 2.89 (.89)).

Regarding germane cognitive load, ME 1 was significant and germane cognitive load was lower (M = 4.53 (.96)) after explanation than before (M = 4.75 (1.01)).

3) Results for RQ 3: To evaluate whether the differences seen in the descriptive results with respect to **RQ 3** reach statistical significance, analyses of variances (ANOVAs) were performed for the four variables (i.e., perceived usefulness for understandability (PUU), perceived ease of understandability (PEU), subjective ease of use (SEU), subjective comprehensibility (SC)). Moreover, Greenhouse-Geisser correction was applied if necessary (i.e., significant Mauchly's sphericity test). The between-subject factor "modularization" had three levels (horizontal, vertical, orthogonal). The main effect (ME) "modularization" for each variable was evaluated. In addition, in the event of significance for ME, Post hoc analyses using the Bonferroni post hoc criterion were employed. Finally, all statistical tests were performed two-tailed and the significance value was set to $p < .05$. Table IX presents the results with respect to **RQ 3**.

TABLE IX
INFERENTIAL STATISTICS FOR RQ 3

ME	Part Two of Study I		
PUU	F(2.00; 92.00)	= 2.96	p = .057
PEU	F(2.; 92.00)	= .34	p = .711
	Part Three of Study I		
SEU	F(2.00; 92.00)	= 4.91	p = .009
SC	F(2.00; 92.00)	= 1.59	p = .209

Note: PUU = Perceived Usefulness for Understandability; PEU = Perceived Ease of Understandability; SEU = Subjective Ease of Use SC = Subjective Comprehensibility

Regarding SEU, there was a significant difference between the modularization types and Post hoc analysis using the Bonferroni post hoc criterion for significance indicated that the frequencies between horizontal (N = 26) and orthogonal (N = 14) modularization differed significantly (p = .007; better for horizontal modularization).

4) Results for RQ 4: To evaluate whether the differences seen in the descriptive results with respect to **RQ 4** reach statistical significance, analyses of variances (ANOVAs) were performed for all four performance measures (i.e., score, duration, fixation, average fixation duration) for each process model (i.e., three in total). Moreover, Greenhouse-Geisser correction was applied if necessary (i.e., significant Mauchly's sphericity test). Thereby, one within-subject factor "model" (three levels: performance measure of process model 1 - 3) and its ME was evaluated. In addition, in the event of significance for ME, repeated contrasts were employed. Finally, all statistical tests were performed two-tailed and the significance value was set to $p < .05$. Table X presents the results with respect to **RQ 4**.

TABLE X
INFERENTIAL STATISTICS FOR RQ 4

ME	Score		
PM 1	F(1.66; 29.93)	= .32	p = .688
PM 2	F(1.98; 35.61)	= .69	p = .507
PM 3	F(1.62; 29.18)	= .60	p = .522
	Duration		
PM 1	F(1.89; 34.00)	= .41	p = .655
PM 2	F(1.99; 35.76)	= 2.14	p = .133
PM 3	F(1.97; 35.40)	= 4.06	p = .026
	Fixation		
PM 1	F(1.74; 31.39)	= .45	p = .618
PM 2	F(1.81; 32.57)	= 4.27	p = .026
PM 3	F(1.88; 33.90)	= 4.69	p = .017
	Fixation Duration		
PM 1	F(1.74; 31.23)	= 2.03	p = .153
PM 2	F(2.00; 35.94)	= .41	p = .668
PM 3	F(1.68; 30.24)	= 23.07	p < .001

Note: ME = Main Effect; PM = Process Model

Regarding duration in the third process model, ME was significant and repeated contrasts showed that horizontal modularization (M = 83.18 (28.84)) had a longer duration (p = .012) than vertical modularization (M = 65.74 (20.69)) but orthogonal modularization (M = 71.27) did not have a longer duration than vertical modularization.

Regarding fixation in the second process model, ME was significant and repeated contrasts showed that horizontal modularization (M = 76.78 (35.06)) had more fixations (p = .014) than vertical modularization (M = 58.82 (19.04)) but orthogonal modularization (M = 64.03 (26.38)) did not have more fixations than vertical modularization. Regarding fixation in the third process model, ME was significant and repeated contrasts showed that horizontal modularization (M = 72.92 (27.54)) had more fixations (p = .006) than vertical modularization (M = 55.72 (17.93)) but orthogonal modularization (M = 61.57 (19.38)) did not have more fixations than vertical modularization.

Regarding average fixation duration in the third process model, ME was significant and repeated contrasts showed that horizontal modularization (M = 258.54 (41.68)) had a longer average fixation duration ($p < .001$) than vertical modularization (M = 208.32 (30.94)) but orthogonal modularization (M = 201.73 (30.41)) did not have a longer average fixation duration than vertical modularization.

D. Discussion

In the context of process model comprehension, the presented two studies investigated the effects of modularization on process model comprehension from a cognitive point of view. Generally, the application of modularization in process models has the purpose to enable a better comprehension of such models by reducing the overall process model complexity (e.g., model size reduction [43]). In this context, an emphasis was put in previous research on the comparison between modularized and non-modularized process models. Thereby, many research applied and investigated the effects of a vertical modularization (i.e., collapsed subprocesses) [28], [23], [24] on the comprehension of process models. However, other modularization types were also the subject of research (i.e., horizontal [25], vertical [24], orthogonal [27]). Therefore, the work at hand extends the vast body of research about the effects of modularization during the comprehension of process models. In the scope of four research questions (i.e., **RQ 1 - RQ 4**; see Section I) the effects of three modularization types (i.e., horizontal, vertical, orthogonal) on process model comprehension were investigated. Thereby, only modularized process models (i.e., in absence of related non-modularized process models) were taken intro consideration (see Section IV-G).

First, in **RQ 1**, we evaluated the effects of different modularization types (i.e., horizontal, vertical, orthogonal) on the cognitive load (i.e., intrinsic, extraneous, germane) during the comprehension of modularized process models. Regarding the descriptive statistics, intrinsic and extraneous cognitive load were on a low to medium level (see Table II) for all modularization types. This indicates an average interactivity of the process model elements (i.e., intrinsic cognitive load) while the representation of modularized process models was perceived as appropriate (i.e., extraneous cognitive load). However, the germane cognitive load was at an above-average level (see Table II) pointing out that the comprehension of modularized process models is a complex endeavor and that participants were confronted with difficulties in handling the information presented in the process models. As a consequence, emphasis should be put on methods for efficient information handling to foster the comprehension of modularized process models by means of the definition of specific schemata for comprehension (e.g., process model comprehension guidelines). Inferential statistics showed that a vertical modularization had a significant higher intrinsic cognitive load (significant ME 2) than a horizontal or orthogonal modularization (see Table VII). More specifically, the application and comprehension of vertical modularization in a process model had a higher inherent level of difficulty regarding the comprehension of such models. This could be due to the high interactivity of the model elements or the modularized parts in a process model. While the process model elements or the modularized parts in a horizontal and orthogonal modularization are defined in the scope of model-dependent structures (e.g., pools, events), however, in vertical modularization, respective model elements or parts are in the scope of a subprocess. Thereby, the subprocess could be considered as an additional process model leading to the effect that two process models instead of one needed to be comprehended properly. In the context of vertical modularization, possible approaches in order to decrease the intrinsic load may be, on one hand, to ensure an appropriate level of prior knowledge in the comprehension of process models. On the other hand, through the simplification of the process model representation by splitting it into short step-by-step representations. Moreover, as proposed in [24], another approach would be the integration of the subprocesses (i.e., removal of the hierarchy) into the complete process model. Thereby, modeling elements of the subprocesses are grouped and highlighted in the model.

Second, in **RQ 2**, the effects of modularization in process models on the cognitive load (i.e., intrinsic, extraneous, germane) after providing an explanation about respective modularization types (i.e., horizontal, vertical, orthogonal) were juxtaposed (i.e., pre- vs. post-explanation). Generally, in the context of ME 2, no significant differences were found for extraneous and germane load, but for intrinsic load a significant difference was found. A reason might be that a learning effect may occurred in Part Two from Study I, since the participants already were confronted with their assigned modularization type in a process model in Part One from Study I. However, regarding ME 1 (see Table VIII), the results revealed a significant higher intrinsic as well as extraneous cognitive load and a significant lower germane cognitive load after providing an explanation about modularization in process models to the participants (i.e., Part Two of Study I) compared to the results related to the cognitive load without any explanation about modularization in process models (i.e., Part One in Study I). This insight is of particular interest as it seems to be that the participants misjudged the level of complexity (i.e., process model element interactivity (i.e., intrinsic load) and representation (i.e., extraneous load)) in the comprehension of modularized process models. More specifically, after providing an explanation about modularization in process models, participants then realized the actual complexity in modularized models. In other words, the element interactivity (e.g., links in horizontal modularization; see Section II) and the form of representation of modularized process models require higher demands on the working memory. However, another indication could be that modularized process models were not correctly or only partially comprehended. With respect to germane cognitive load, a decrease was observable. This might be an indication that an explanation about modularized process models fosters the mental process of comprehending presented information in modularized process models. Further, the same could be observed in intrinsic and extraneous cognitive load in the descriptive results obtained of Part Three from Study II (see Table VI). With respect to germane cognitive load of Part Three from Study II, however, the results showed a lower germane cognitive load compared to the ones of Part One from Study I (see Table II). An explanation for this might be that the participants in Study II were confronted with a comprehension task. In more detail, they needed to answer a set of comprehension questions for each modularized process model. Consequently, this may have led to the participants studying at and comprehending the modularized process models more effectively, as the objectives between Studies I and II were different (i.e., pure comprehension vs. comprehension performance). To sum up, these observations confirm that an explanation of modularization in process models fosters the handling of information presented in such models (i.e., germane load). In addition, the results indicated, as known from other research (e.g., [28], [23], [27]) that modularized process models can be comprehended intuitively. However, for a correct and complete comprehension, an explanation about the application of modularization is mandatory. The reason is that that the results regarding intrinsic and extraneous load revealed that modularized process models pose specific challenges regarding their proper comprehension (e.g., higher demands on the working memory). In general, the results indicate that when applying modularization in process models three aspects may be of importance in order to ensure a proper comprehension of such models: ① The representation of modularized process models should be amended accordingly to make the information presented in modularized models more receptive (e.g., using colors). ② The provision of proper explanations about modularization in process models to enable and facilitate the conceptualization of memory schemata for the purpose of a better comprehension of modularized process models. ③ The definition of an objective why modularized process models needed to be comprehended.

Third, in **RQ 3**, the level of acceptability of modularization in process models was investigated. Therefore, we addressed the perceived usefulness for understandability (PUU) as well as the perceived ease of understandability (PEU) in Part Two of Study I and the subjective ease of use (SEU) as well as the subjective comprehensibility (SC) in Part Three of Study I. The results for PUU and PEU were similar in all three modularization types (i.e., horizontal, vertical, orthogonal) and were on average (see Table III). That means that participants were undecided about how modularization fosters the comprehension of such process models. Moreover, it appears that the attitude toward using as well as the intention to use modularization in process models is still unclear and possibly even questionable. Similar effect was observed by the authors in [24] in the context of vertical modularization. To counteract this, it would be beneficial to elaborate the purpose as well as the benefits of modularization in process models in more detail. In contrast, considering the results obtained of Part Three from Study II (see Table VI), the descriptive results regarding PUU and PEU were lower compared to the results from Study I (see Table III). Taking into account that the participants from Study I were confronted with more information about modularized process models that may have had a positive effect on PUU and PEU, the results from Study II revealed as well that the use and the benefits of the application of modularization in process models is not clear. Furthermore, regarding SEU, a significant difference was found (see Table IX) and participants indicated that a horizontal modularization in process models reflected a higher subjective ease of use compared to orthogonal modularization. This can be explained by the fact that the horizontal modularization decomposes a process model in smaller modules (i.e., process models) in order to foster the reusability as well as the comprehensibility in general. At the same time, the decomposition into smaller modules decreases the inherent process model complexity that may result in a higher ease of use, since the comprehension of smaller modules is associated with less cognitive load. However, note that this aspect, in turn, may cause opposing effects in the modularization of process models (e.g., split-attention effect [63]). In general, such impairing effects should be considered in modularized process models (see Section IV-G) [43]. Although the inferential statistics revealed no significant differences, however, from the descriptive statistics the results for SC confirm the observations made regarding SEU (see Table IV). More specifically, participants indicated, based on subjective preferences, that a horizontal modularization in process models is the best comprehensible juxtaposed to vertical or orthogonal modularization.

Fourth, in **RQ 4**, the four performance measures (i.e., score, duration, fixation, average fixation duration) were observed in an eye tracking study in which all three modularization types (i.e., horizontal, vertical, orthogonal) were presented to the participants in a comprehension task. While the results for vertical and orthogonal modularization were similar, however, certain horizontal modularized process models showed significant differences (see Table X). In particularly, participants, for certain horizontal modularized process models, needed more time to comprehend, showed a higher number of fixations as well as a longer average fixation duration. These results indicated that participants were confronted with a higher cognitive load during the comprehension of process models representing a horizontal modularization. However, compared to the results of **RQ 1 - 3** obtained in Study I, in which horizontal modularization is associated with a low cognitive load, the results from the eye tracking study were contradictory related to the cognitive load. In more detail, participants from Study I indicated that process models with horizontal modularization were better comprehensible than process models in vertical or orthogonal modularization (see Table IV). However, comprehension performance measures (e.g., comprehension duration) in Study II revealed that participants needed more effort to get to grips with horizontal modularized process models. Nevertheless, the participants indicated that horizontal modularization in process models appears to be the best comprehensible modularization type (see Section IV-A). Therefore, in the light of the results obtained in Studies I and II, the application of horizontal modularization in process models may lead to a more fine-grained comprehension of such models, since it must be ensured that the smaller process model modules but also the entire process model is comprehended properly . Further, regarding the achieved score in the comprehension questions, the obtained results for all modularization types were 3.50 (i.e., 4 is max) on average (see Table V). Same es in **RQ 1**, modularized process models could be comprehended intuitively [27], [50].

Finally, Tab. XI summarizes our general findings obtained for each research question (i.e., RQ 1 - 4) in Studies I and II.

E. Limiting Factors

Several limiting factors were encountered during the execution of Studies I and II. First, the modularized process models might not be representative. Usually, process models document procedures of the real world, which are far more complex (e.g., high information density). However, the used process models in Studies I and II were kept simple intentionally (i.e., average number of modeling elements < 50). Thereby, research showed that process model comprehension becomes error-prone from 50 modeling elements [64]. Consequently, complex process models make different demands regarding, for example, the cognitive load and the level of acceptability juxtaposed to less complex process models. Moreover, second, the scenarios documented in respective process models represent another limitation. Most of the scenarios in the process models used in Studies I and II are common. Hence, an unfamiliar scenario in a process model might has a negative effect on process model comprehension in comparison with a familiar scenario. Third, the inherent difficulty (e.g., process model complexity, question difficulty) of the study material may not be appropriate. In detail, the true-or-false comprehension questions might be too easy, since the participants had almost reached the maximum score in answering these questions. Fourth, another limitation were the participants of both studies. Specifically, only students with varying expertise in process modeling (see Table I) were evaluated and, hence, generalizability is limited. Fifth, the sample sizes limit the statistical power and there might be significant differences between Study I and Study II, which we could not detect, but which might become apparent in larger sample sizes. In addition, the number of participants in Studies I and II was not the same and, hence, there was an imbalance. Sixth, as procedures of Studies I and II were not the same there might be a potential risk of validity in the comparison of the assessed performance measures. Seventh, no block randomization was used in Study I, but only a randomization function provided by Google Forms. Therefore, no balance in the modularization groups (i.e., N = 35 for horizontal, N = 32 for vertical, and N = 28 for orthogonal modularization) was achieved and, in addition, it could not be ensured that all three groups share similar characteristics (e.g., experience). Eight, in Study I, since participants were confronted with several modularized process models, a learning effect could have occurred that affected results regarding the cognitive load as well as the level of acceptability. Ninth, although a reduction in the cognitive load during process model comprehension can be achieved with the application of modularization (e.g., reduction of process model complexity), however, other cognitive effects may emerge, which in turn have a negative effect on the comprehension of such models. For example, the depiction of a process model into smaller process models leads to the circumstance that the attention of an individual must be split between the smaller modules in order to ensure a proper model comprehension (i.e., split-attention effect [63]). As a result, the split attention may cause a higher cognitive load [43]. Tenth, similar as in ninth, since the participants in Study I (see Section III-D) could complete the online survey using any mobile device (e.g., laptop, smartphone), hence this fragmentation constituted another risk especially in Study I. In more detail, due to the different screen sizes (laptop vs. smartphone), the process models could be displayed completely without the need for further actions (e.g., scrolling), which, in turn, could have led to an impairment during process model comprehension. Finally, while results look promising, additional studies are needed in order to confirm the generalization of the results.

F. Implications

The provided insights have implications for research on process model comprehension as well as for practice by investigating the effects of modularization in process models.

For research: With the results from this work as theoretical foundation, research may focus on the replication of the presented studies with the use of more complex process models. More complex process models should have a stronger effect on the cognitive load (i.e., intrinsic, extrinsic, germane), as more information needs to be processed in the working memory. Consequently, with the insights obtained from other studies (e.g., [24]), concrete efforts can be made in order to reduce the cognitive load in general, especially when dealing with complex modularized process models. Moreover, changes in the overall representation based on model design guidelines (e.g., [23]) of respective modularization types could be implemented and their repercussions on process model comprehension or on the cognitive load could be investigated in additional studies. Moreover, an emphasis can be put on the intrinsic as well as extraneous load to achieve a significant load reduction in these two dimensions. Possible approaches would be to address the modeling element interactivity (e.g., reduce number of connecting elements) or with changes in the overall representation (e.g., application of colors). Furthermore, the question arises whether various domain experts (e.g., modeling experts vs. doctors) perceive modularization in process models differently in comparison with each other. In addition, the combination of different modularization types (e.g., horizontal + orthogonal) might open a novel perception of modularization, having a divergent effect on process model comprehension, compared to the previous approaches. The analysis of recorded eye movement could reveal novel insights. For example, are there different and common strategies (e.g., back-and-forth saccade jumps) in the comprehension of modularized process models. Finally, it would be interesting to investigate whether the same effects of the three modularization types (i.e., horizontal, vertical, orthogonal) as presented in this work can be observed in other modeling notations.

For practice: Prior work already highlighted the benefits of modularized process models in a practical context [21]. With the work at hand, we extend existing research in this context and highlight the challenges of the application of modularization in process models. However, in practice, in order to make use of the advantages of modularization, efforts should be made to increase the attitude towards using as well as the

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

TABLE XI
SUMMARY OF FINDINGS IN STUDIES I AND II

Research Question		Denouement
RQ 1:	Cognitive Load	Intrinsic (i.e., modeling element interactivity; highest in vertical modularization) and extraneous (i.e., presentation) load were on a low to medium level, whereas germane load (i.e., mental effort) was above-average indicating that participants were confronted with challenges in the comprehension of modularized process models.
RQ 2:	Cognitive Load (Post-Explanation)	Intrinsic and extraneous load were significant higher, while germane load was significant lower after presenting an explanation about modularization. Accordingly, participants misjudged the complexity of modularized process models, but an explanation about modularization may foster the construction of mental models for the proper comprehension of presented information in modularized process models
RQ 3:	Level of Acceptability	Participants were undecided about the benefits of modularization in process models. Amongst all three types, horizontal modularization appears to be the best comprehensible.
RQ 4:	Performance	Obtained results were similar, but implied that the application of horizontal modularization in process models led to a more fine-grained comprehension in general. Further, modularized process models can be comrehended intuitively.

behavioral intention to use modularization in process models. Moreover, an awareness must be raised to model processes from the very beginning in a modularized way. Therefore, modularization in process models must be explained precisely to practitioners and, accordingly, attention must be paid that modularization is applied correctly in order to avoid possible later consequences. In this way, performance and efficiency in working with process models can be increased due to an overall lower cognitive load. The two studies revealed only few significant differences regarding the three modularization types and, hence, the choice about which type of modularization to use can be made based on subjective preferences, since there were only little differences in terms of comprehension performance. However, the results indicated that horizontal modularization is a more preferable choice.

G. Future Work

While the results obtained from both studies provide new exploratory insights about the effects of different types of modularization (i.e., horizontal, vertical, orthogonal) in process models, their generalization needs to be confirmed by additional studies, e.g., in order to obtain more accurate results allowing such a generalization, additional studies are needed either through replication or similar studies in other environments or with different samples. Regarding the latter, domain experts from different fields (e.g., physicians, therapists) would represent an appropriate sample. In this context, it would be interesting to investigate the influence of process model expertise in working with modularized models. Moreover, since process models from the real world usually are more complex than the process models used in Studies I and II, further studies may investigate the effects of modularization in complex real-world process models, which are taken from organizations. This could include, for example, a comparison between modularized and non-modularized process models in order to emphasize the effects of modularized process models. Other types of modularization (e.g., composition), the combination of different modularization types (e.g., horizontal + orthogonal), or a change in their representation (e.g., design) could be the subject of further research in order to improve our understanding of modularization in process models. Further, modularization in process models and their effects should also be considered based on other function (e.g., role-based). Moreover, a special emphasis should be put on the cognitive load and its related dimensions (i.e., intrinsic, extraneous, germane) in order to achieve a reduction in the related dimensions that should lead to a better comprehension of modularized process models. In this context, the consideration of other cognitive effects (e.g., split-attention effect, worked-example effect [65]) will allow for the identification of new insights, enabling a better assistance (e.g., comprehension guidelines, tool support) in the comprehension of modularized process models. In addition, another emphasis will be put on the analysis of eye tracking measures (e.g., fixation) in order to examine comprehension strategies (e.g., back-and-forth saccade jumps). Thereby, fixation time variabilities as well as scan path patterns may be another indicator for the determination of the cognitive load in this context. Moreover, in order to double-check the results, the investigation of the effects of modularization in other process modeling languages (e.g., Event-driven Process Chains, UML Activity Diagram) will be subject of future work. Finally, a similar study is in preparation regarding modularization using a data-centric modeling approach [66]. Finally, for the future, we plan the replication of the presented studies in a real-world scenario. Therefore, practitioners from industry will be invited and process models derived from practice are planned to be used.

V. CONCLUSION

This paper presented the effects of three modularization types (i.e., horizontal, vertical, orthogonal) on the comprehension of BPMN 2.0 process models. Particularly, in the scope of four research questions (i.e., **RQ 1 - RQ 4**), the cognitive load (i.e., intrinsic, extraneous, germane), the level of acceptability (i.e., perceived usefulness for understandability, perceived ease of understandability, subjective ease of use, subjective comprehensibility) and the performance (i.e., score, duration, number of fixations, average fixation duration) in process model comprehension were investigated in two exploratory studies (i.e., Study I was conducted as a survey research study with N = 95 participants and Study II as an eye tracking study with N = 19 participants) using modularized process models. In general, all three modularization types had similar effects on the cognitive load and its related dimensions, the level of acceptability, and on the performance in process model comprehension. However, subjectively, the results obtained from the participants suggested to prefer a horizontal modularization in process models. Taking a closer look at the results, they revealed that participants were confronted with different challenges (e.g., process model elements interactivity, creation of mental schemata) while comprehending modularized process models. Furthermore, as an interesting finding found in both studies is that participants misjudged the inherent level of complexity of modularization in process models. In more detail, modularization was perceived less complex initially (i.e., low cognitive load). After an explanation about the correct application of modularization in process models, the participants realized the true complexity of modularized process models resulting in a significant higher cognitive load. Moreover, the results showed that participants were hesitant about the application and related benefits of modularized process models. Therefore, with this work, we underline the importance of specific alterations (e.g., provision of a thorough explanation) about modularization in process models and to further study the role of the cognitive load as well as level of acceptability in this context.

REFERENCES

[1] M. Yli-Ojanperä, S. Sierla, N. Papakonstantinou, and V. Vyatkin, "Adapting an agile manufacturing concept to the reference architecture model industry 4.0: A survey and case study," *Journal of Industrial Information Integration*, vol. 15, pp. 147–160, Sept. 2019.

[2] D. Domingos, A. Respício, and R. Martinho, *Reliability of IoT-aware BPMN healthcare processes*. IGI Global, Apr. 2020, pp. 793–821.

[3] A. Polyvyanyy, S. Smirnov, and M. Weske, "Process model abstraction: A slider approach," in *Proc. 12th Int. Conf. on Enterprise Distributed Object Computing (EDOC)*, Munich, GER, 2008, pp. 325–331.

[4] J. Ghattas, P. Soffer, and M. Peleg, "Improving business process decision making based on past experience," *Decision Support Systems*, vol. 59, pp. 93–107, March 2014.

[5] M. Zimoch, R. Pryss, T. Probst, W. Schlee, and M. Reichert, "The repercussions of business process modeling notations on mental load and mental effort," in *Proc. 11th Int. Wksh. on Social and Human Aspects of Business Process Management (BPMS)*, Sydney, AUS, 2018, pp. 133–145.

[6] K. Figl, "Comprehension of procedural visual business process models," *Business & Information Systems Engineering*, vol. 59, no. 1, pp. 41–67, Jan. 2017.

[7] H. A. Reijers and J. Mendling, "A study into the factors that influence the understandability of business process models," *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, vol. 41, no. 3, pp. 449–462, May 2011.

[8] K. Figl, J. Mendling, and M. Strembeck, "The influence of notational deficiencies on process model comprehension," *Journal of the Association for Information Systems*, vol. 14, no. 6, June 2013.

[9] M. Dumas, M. La Rosa, J. Mendling, R. Mäesalu, H. A. Reijers, and N. Semenenko, "Understanding business process models: the costs and benefits of structuredness," in *Proc. 24th Int. Conf. on Advanced Information Systems Engineering (CAiSE)*, Gdansk, PL, 2012, pp. 31–46.

[10] J. Mendling, M. Strembeck, and J. Recker, "Factors of process model comprehension-findings from a series of experiments," *Decision Support Systems*, vol. 53, no. 1, pp. 195–206, Apr. 2012.

[11] T.-F. Kummer, J. Recker, and J. Mendling, "Enhancing understandability of process models through cultural-dependent color adjustments," *Decision Support Systems*, vol. 87, pp. 1–12, July 2016.

[12] F. J. Varela, E. Thompson, and E. Rosch, *The embodied mind: Cognitive science and human experience*, 2nd ed. MIT press, 2017.

[13] C. E. Zsambok and G. Klein, *Naturalistic decision making*, 1st ed. Psychology Press, 2014.

[14] Y. Wang, "Cognitive complexity of software and its measurement," in *Proc. 5th IEEE Int. Conf. on Cognitive Informatics (ICCI)*. Beijing, CHN, 2006, pp. 226–235.

[15] Y. Wang, "On the cognitive complexity of software and its quantification and formal measurement," *International Journal of Software Science and Computational Intelligence*, vol. 1, no. 2, pp. 31–53, 2009.

[16] M. Tallon, M. Winter, R. Pryss, K. Rakoczy, M. Reichert, M. W. Greenlee, and U. Frick, "Comprehension of business process models: Insight into cognitive strategies via eye tracking," *Expert Systems with Applications*, vol. 136, pp. 145–158, Dec. 2019.

[17] K. Figl and J. Recker, "Exploring cognitive style and task-specific preferences for process representations," *Requirements Engineering*, vol. 21, no. 1, pp. 63–85, Sept. 2014.

[18] R. Petrusel, J. Mendling, and H. A. Reijers, "How visual cognition influences process model comprehension," *Decision Support Systems*, vol. 96, pp. 1–16, Apr. 2017.

[19] M. Zimoch, R. Pryss, J. Schobel, and M. Reichert, "Eye tracking experiments on process model comprehension: lessons learned," in *Proc. 18th Int. Wksh. on Business Process Modeling, Development and Support (BPMDS)*. Essen, GER: Springer, 2017, pp. 153–168.

[20] R. Petrasch and R. Hentschke, "Process modeling for industry 4.0 applications: Towards an industry 4.0 process modeling language and method," in *Proc. 13th Int. Joint Conf. on Computer Science and Software Engineering (JCSSE)*, Khon Kaen, THA, 2016, pp. 1–5.

[21] C. Gärtner and O. Schön, "Modularizing business models: between strategic flexibility and path dependence," *Journal of Strategy and Management*, vol. 9, no. 1, pp. 39–57, Feb. 2016.

[22] J. B. Dahmus, J. P. Gonzalez-Zugasti, and K. N. Otto, "Modular product architecture," *Design studies*, vol. 22, no. 5, pp. 409–424, 2001.

[23] H. Reijers and J. Mendling, "Modularity in process models: Review and effects," in *Proc. 6th Int. Conf. on Business Process Management (BPM)*, Milan, IT, 2008, pp. 20–35.

[24] O. Turetken, A. Dikici, I. Vanderfeesten, T. Rompen, and O. Demirors, "The influence of using collapsed sub-processes and groups on the understandability of business process models," *Business & Information Systems Engineering*, vol. 62, pp. 121–141, 2019.

[25] F. Johannsen and S. Leist, "Wand and weber's decomposition model in the context of business process modeling," *Business & Information Systems Engineering*, vol. 4, no. 5, pp. 271–286, 2012.

[26] H. A. Reijers, J. Mendling, and R. M. Dijkman, "Human and automatic modularizations of process models to enhance their comprehension," *Information Systems*, vol. 36, no. 5, pp. 881–897, 2011.

[27] C. Cappelli, F. M. Santoro, J. C. S. do Prado Leite, T. Batista, A. L. Medeiros, and C. S. Romeiro, "Reflections on the modularity of business process models," *Business Process Management Journal*, vol. 16, no. 1, pp. 662–687, 2010.

[28] O. Turetken, T. Rompen, I. Vanderfeesten, A. Dikici, and J. van Moll, "The effect of modularity representation and presentation medium on the understandability of business process models in bpmn," in *Proc. 14th Int. Conf. on Business Process Management (BPM)*. Rio de Janeiro, BRA, 2016, pp. 289–307.

[29] R. N. Langlois, "Modularity in technology and organization," *Journal of economic behavior & organization*, vol. 49, no. 1, pp. 19–37, Sept. 2002.

[30] J. Bonvoisin, F. Halstenberg, T. Buchert, and R. Stark, "A systematic literature review on modular product design," *Journal of Engineering Design*, vol. 27, no. 7, pp. 488–514, Mar. 2016.

[31] C. Y. Baldwin, K. B. Clark, K. B. Clark *et al.*, *Design rules: The power of modularity*. MIT press, 2000, vol. 1.

[32] M. Efatmaneshnik, S. Shoval, and L. Qiao, "A standard description of the terms module and modularity for systems engineering," *IEEE Transactions on Engineering Management*, vol. 67, no. 2, pp. 365–375, 2020.

[33] H. Ahmadzadeh, E. Masehian, and M. Asadpour, "Modular robotic systems: characteristics and applications," *Journal of Intelligent & Robotic Systems*, vol. 81, pp. 317–357, June 2016.

[34] M. V. Martin and K. Ishii, "Design for variety: developing standardized and modularized product platform architectures," *Research in Engineering Design*, vol. 13, no. 4, pp. 213–235, Nov. 2002.

[35] F. Milani, M. Dumas, N. Ahmed, and R. Matulevičius, "Modelling families of business process variants: A decomposition driven method," *Information Systems*, vol. 56, pp. 55–72, Mar. 2016.

[36] J. Vanhatalo, H. Völzer, and F. Leymann, "Faster and more focused control-flow analysis for business process models through sese decomposition," in *Proc. 5th Int. Conf on Service Oriented Computing (ICSOC)*, Vienna, AU, 2007, pp. 43–55.

[37] F. Milani, M. Dumas, R. Matulevičius, N. Ahmed, and S. Kasela, "Criteria and heuristics for business process model decomposition," *Business & Information Systems Engineering*, vol. 58, no. 1, pp. 7–17, Dec. 2015.

[38] A. Jalali, C. Ouyang, P. Wohed, and P. Johannesson, "Supporting aspect orientation in business process management," *Software & Systems Modeling*, vol. 16, no. 3, pp. 903–925, 2017.

[39] A. Charfi and M. Mezini, "Aspect-oriented workflow languages," in *Proc. Int. Conf. on Cooperative Information Systems (CoopIS)*. Montpellier, FRA, 2006, pp. 183–200.

[40] L.-O. Johansson, M. Wärja, and S. Carlsson, "An evaluation of business process model techniques, using moody's quality criterion for a good diagram," in *Proc. 11th Int. Conf. on Perspectives Business Informatics Research (BIR)*, vol. 963. Nizhny Novgorod, RUS, 2012, pp. 54–64.

[41] M. La Rosa, P. Wohed, J. Mendling, A. H. Ter Hofstede, H. A. Reijers, and W. M. van der Aalst, "Managing process model complexity via abstract syntax modifications," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 614–629, Sept. 2011.

[42] B. Weber, M. Reichert, J. Mendling, and H. A. Reijers, "Refactoring large process model repositories," *Computers in Industry*, vol. 62, no. 5, pp. 467–486, Jun. 2011.

[43] A. Dikici, O. Turetken, and O. Demirors, "Factors influencing the understandability of process models: A systematic literature review," *Information and Software Technology*, vol. 93, pp. 112–129, Jan. 2018.

[44] A. Kellens, K. Mens, J. Brichau, and K. Gybels, "Managing the evolution of aspect-oriented software with model-based pointcuts," in *Proc. 20th Euro. Conf. on Object-Oriented Programming (ECOOP)*. Nantes, FRA, 2006, pp. 501–525.

[45] H. Witteborg, A. Charfi, D. C. Collell, and M. Mezini, "Weaving aspects and business processes through model transformation," in *Proc. 3rd Euro. Conf. on Service-Oriented and Cloud Computing (ESOCC)*. Manchester, UK, 2014, pp. 47–61.

[46] C. Cappelli, J. C. Leite, T. Batista, and L. Silva, "An aspect-oriented approach to business process modeling," in *Proc. 15th Wksh on Early Aspects (EA)*. Charlottesville, USA, 2009, pp. 7–12.

[47] OMG, Object Management Group Specification. (2020, Apr.) Business Process Modeling & Notation 2.0. [Online]. Available: https://www.bpmn.org

[48] ISO/IEC 19510:2013, "Information technology — Object Management Group Business Process Model and Notation," International Organization for Standardization, Standard, 2013.

[49] F. Corradini, A. Ferrari, F. Fornari, S. Gnesi, A. Polini, B. Re, and G. O. Spagnolo, "A guidelines framework for understandable bpmn models," *Data & Knowledge Engineering*, vol. 113, pp. 129–154, 2018.

[50] M. Zimoch, R. Pryss, T. Probst, W. Schlee, and M. Reichert, "Cognitive insights into business process model comprehension: preliminary results for experienced and inexperienced individuals," in *Proc. 18th Int. Wksh. on Business Process Modeling, Development and Support (BPMDS)*. Essen, GER: Springer, 2017, pp. 153–168.

[51] M. Zur Muehlen and J. Recker, "How much language is enough? theoretical and practical use of the business process modeling notation," in *Proc. 20th Int. Conf. on Advanced Information Systems Engineering (CAiSE)*, Montpellier, Fra, 2013, pp. 429–443.

[52] J. Sweller, "Cognitive load theory, learning difficulty, and instructional design," *Learning and Instruction*, vol. 4, no. 4, pp. 295–312, 1994.

[53] F. Paas, A. Renkl, and J. Sweller, "Cognitive load theory and instructional design: Recent developments," *Educational psychologist*, vol. 38, no. 1, pp. 1–4, 2003.

[54] M. Klepsch, F. Schmitz, and T. Seufert, "Development and validation of two instruments measuring intrinsic, extraneous, and germane cognitive load," *Frontiers in Psychology*, vol. 8, Nov. 2017.

[55] W. R. King and J. He, "A meta-analysis of the technology acceptance model," *Information & Management*, vol. 43, no. 6, pp. 740–755, Sept. 2006.

[56] O. Turetken, J. Ondracek, and W. IJsselsteijn, "Influential characteristics of enterprise information system user interfaces," *Journal of Computer Information Systems*, vol. 59, no. 3, pp. 243–255, 2019.

[57] J. Mendling, J. Recker, H. A. Reijers, and H. Leopold, "An empirical review of the connection between model viewer characteristics and the comprehension of conceptual process models," *Information Systems Frontiers*, vol. 21, no. 5, pp. 1111–1135, 2019.

[58] I. Krajbich, C. Armel, and A. Rangel, "Visual fixations and the computation and comparison of value in simple choice," *Nature Neuroscience*, vol. 13, no. 10, pp. 1292–1298, Sept. 2010.

[59] J. M. Henderson, W. Choi, S. G. Luke, and J. Schmidt, "Neural correlates of individual differences in fixation duration during natural reading," *Quarterly Journal of Experimental Psychology*, vol. 71, no. 1, pp. 314–323, May 2017.

[60] A. Korbach, R. Brünken, and B. Park, "Differentiating different types of cognitive load: A comparison of different measures," *Educational Psychology Review*, vol. 30, no. 2, pp. 503–529, Mar. 2017.

[61] C. Wohlin, P. Runeson, M. Höst, M. C. Ohlsson, B. Regnell, and A. Wesslen, *Experimentation in Software Engineering - An Introduction*, 1st ed. Kluwer, 2012.

[62] Google. (2020, Apr.) Google Forms. [Online]. Available: https://www.google.com/forms/about/

[63] W. Pouw, G. Rop, B. De Koning, and F. Paas, "The cognitive basis for the split-attention effect." *Journal of Experimental Psychology: General*, vol. 148, no. 11, pp. 2058–2075, 2019.

[64] J. Mendling, G. Neumann, and W. Van Der Aalst, "Understanding the occurrence of errors in process models based on metrics," in *Proc. Int. Conf. on Cooperative Information Systems (CoopIS)*. Vilamoura, POR, 2007, pp. 113–130.

[65] O. Chen, S. Kalyuga, and J. Sweller, "The worked example effect, the generation effect, and element interactivity." *Journal of Educational Psychology*, vol. 107, no. 3, p. 689, 2015.

[66] S. Steinau, A. Marrella, K. Andrews, F. Leotta, M. Mecella, and M. Reichert, "Dalec: a framework for the systematic evaluation of data-centric approaches to process management software," *Software & Systems Modeling*, vol. 18, no. 4, pp. 2679–2716, sept. 2018.

Michael Winter studied Computer Science at Ulm University and has been working there as a research associate since 2015. His main research focus is on the topic of business process management. He focuses on the creation and particularly on the comprehension of visual process models. In this context, he applies measurement methods as well as theories from cognitive neuroscience (e.g., eye tracking, electrodermal activity) and psychology (e.g., Cognitive Load Theory) to unravel new insights. Therefore, he developed a conceptual framework to foster and to assist novices as well as experts in the comprehension of process models. In addition, he utilizes approaches from different domains (e.g., serious game) in various studies as well in order to ensure a proper and correct comprehension of process models.

Prof. Dr. Rüdiger Pryss studied at the Universities of Passau, Karlsruhe and Ulm. He holds a Diploma in Computer Science. After graduating, he worked as a consultant and developer in a software company. Since 2008, he has been a research associate at Ulm University. In 2015, he received a PhD in Computer Science. In his doctoral thesis, Rüdiger focused on fundamental issues related to mobile process and task support. Rüdiger was local organization chair of the BPM'09 and EDOC'14 conferences. Moreover, he is experienced with teaching courses on database management, programming, service-oriented computing, business process management, document management, and mobile application engineering. In 2019, Rüdiger Pryss was appointed as full professor in medical informatics at the University of Würzburg.

Prof. Dr. Thomas Probst studied Psychology at Regensburg University. He holds a Diploma in Psychology. After graduating, he started his psychotherapy training and received his certification as cognitive-behavior therapist in 2013. Between 2013 and 2015, he worked at Regensburg University (research assistant and deputy head of the psychotherapy outpatient center). In 2015, he received a PhD in Psychology at the Humboldt-University of Berlin. In his doctoral thesis, Thomas focused on psychotherapy monitoring, patient-therapist feedback, and decision support tools. From 2015 to 2016, he was Interim Professor for Clinical Psychology and Psychotherapy as well as for Clinical Psychodiagnostics at the University Witten/Herdecke. In 2017, he was Interim Professor at the Georg-August-University Göttingen and research associate at Ulm University. At 2017, he was appointed as Professor for Psychotherapy Sciences at the Danube University Krems, Austria. Moreover, he is experienced with teaching courses on psychotherapy and psychodiagnostics, psychosomatics, digital health, quantitative research designs.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TCDS.2020.3032730, IEEE Transactions on Cognitive and Developmental Systems

Julia Baß studied Media Informatics at Ulm University. In addition to the research on process model comprehension, a focus of interest of Julia is the field of psychology. Here, she evaluated the cognitive load, usability, and user experience of learning management systems. Furthermore, in the context of eye tracking, she investigated approaches regarding pupil-based biofeedback and examined eye-movements during the comprehension of process models.

Prof. Dr. Manfred Reichert holds a PhD in Computer Science and a Diploma in Mathematics. Since 2008 he has been appointed as full professor at the University of Ulm, where he is director of the Institute of Databases and Information Systems. Before, he was working as associate professor at the University of Twente in the Netherlands. There, he was also a member of the management board of the Centre for Telematics and Information Technology, which is one of the largest academic ICT research institutes in Europe. Manfred's research interests include business process management (e.g., adaptive and flexible processes, process lifecycle management, data-driven and object-centric processes) and service-oriented computing (e.g., service interoperability, mobile services, service evolution). He has been PC Co-chair of the BPM'08, CoopIS'11, EMISA'13 and EDOC'13 conferences, and General Chair of the BPM'09 and EDOC'14 conferences.