Using Secondary Notation to Influence the Model User's Attention

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Dipl.-Wirt.-Inf. Jeannette Stark
geb. 20.11.1980

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Gutachter:
Prof. Dr. Werner Esswein
Prof. Dr. Susanne Strahringer

Preface

Daniel Moody legte 2009 mit seiner Arbeit “Physics of Notations” den Grundstein für viele Arbeiten, die zur Verbesserung der konkreten grafischen Syntax beitrugen. Mit diesem Werk legte er darüber hinaus das theoretische Fundament für die konkrete grafische Syntax und ermöglichte somit den Diskurs zu dem Thema dieser Dissertation. Die „Physics of Notations“ beinhaltet neun Prinzipien zur Verbesserung der kognitiven Effizienz der konkreten grafischen Syntax von Modellierungsgrammatiken. Diese Arbeit erweitert das Prinzip der Perzeptiven Unterscheidbarkeit mit dem Fokus, Aufmerksamkeit auf die Dinge zu richten, die für das Modellverständnis von Bedeutung sind. Zu diesem Ziel wurden Forschungsergebnisse aus den Gebieten der Visuellen Aufmerksamkeit, der Farbtheorien und der Farbharmonie recherchiert, aufbereitet und schließlich auf das Gebiet der Konzeptuellen Modellierung angewendet.

Diese Arbeit wäre ohne die Hilfe vieler Beteiligter nicht möglich gewesen. Ein großer Dank gebührt meinem Doktorvater, Prof. Dr. Werner Esswein, der mich sehr stark in meiner Zielorientierung unterstützte, vielfältige Anregungen und Ideen lieferte und mir bei der Beantragung für ein Abschlussstipendium mit einem Gutachten half. Meiner Zweitgutachterin Prof. Dr. Susanne Strahringer danke ich insbesondere für Ihre wertvollen Hinweise für diese Arbeit und für die Beantragung für das Abschlussstimpendium, sowie für Ihr Gutachten für dieses. Für zahlreiche Gespräche standen mir in erster Linie mein Doktorvater Prof. Dr. Werner Esswein und meine Kollegen zur Verfügung, die mir ihre Wahrnehmung über bestimmte Gestaltungsideen im Rahmen dieser Arbeit immer wieder beschreiben mussten, darüber hinaus vielfältige Anregungen zur Weiterarbeit gaben und für Vortests der Experimente zur Verfügung standen. Insbesondere danke ich auch meinem Kollegen Richard Braun für die vielen Gespräche über unsere beiden Arbeiten und meiner Kollegin Lisa Gerstenberger für ihre wertvolle Unterstützung im Arbeitsalltag.

Weiterhin danke ich meiner Familie. Mein Mann ermöglichte mir das Arbeiten an vielen Abenden und Wochenenden zum Schluss dieser Arbeit und vor den Deadlines der einzelnen Beiträge, indem er die vielen Stunden allein für unsere Kinder sorgte. Darüber hinaus danke ich auch meinen Schwiegereltern, die uns mit der Kinderbetreuung stark unterstützten und meinen Eltern und Kindern, mit denen wir in dieser Zeit wunderbare Erlebnisse und schöne Stunden teilten, die für eine Weiterarbeit unbedingt notwendig waren.

Abstract

Recently cognitive principles have been discussed for Conceptual Modeling with the aim to increase domain understanding, model comprehension and modeling efficiency. In particular, the principle of Perceptual Discriminability, which discusses the visual differences of modeling constructs, reveals potential for model comprehension if human attention is influenced in a way that important modeling constructs are more easily detected, and can hence faster be processed. Yet, so far no conditions how the human gaze can be influenced have been defined and evaluated for Conceptual Modeling. This dissertation extends Perceptual Discriminability for conditions to attract human attention for those constructs that are important for model comprehension. Furthermore, these conditions are applied to constructs of two different modeling grammars in general as well as to elements of the process flow of Business Process Models. To evaluate the results a laboratory experiment of extended Perceptual Discriminability is described in which significant differences have been identified for process flow comprehension. For the demonstration of the potential of extended Perceptual Discriminability BPMN secondary notation is improved by emphasizing those constructs that are most important for model comprehension. Therefore, those constructs that are important for model comprehension have been identified within a content analysis and have been worked on according to the conditions of extended Perceptual Discriminability for those visual variables that are free for an application in secondary notation.

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BPM ..... *Business Process Models*
BPMN ..... *Business Process Modeling Notation*
EPC ..... *Event-driven process chain*
ERD ..... *Entity-Relationship Diagram*
OMG ..... *Obejct Management Group*

PART 1 – SUMMARY PAPER

1. Motivation

Conceptual models are widely accepted for information systems design [1] and can lead to benefits that include process improvement, communication and shared understanding [2]. To gain such benefits modelers normally use a tool-specific implementation of a modeling grammar to develop their models [3-4] (see Fig. 1). The tool-specific implementation is usually based on a primary notation of a modeling grammar, such as the Business Process Modeling Notation (BPMN) [5-6] or the Event-driven Process Chain (EPC) [7], which is defined by notation designers and includes graphical symbols that visually represent modeling constructs with a defined semantic [8-9]. Modelers can already use the resulting modeling grammar and combine its semantic constructs according to defined rules within a conceptual model [3],[9] if they draw their models by hand.

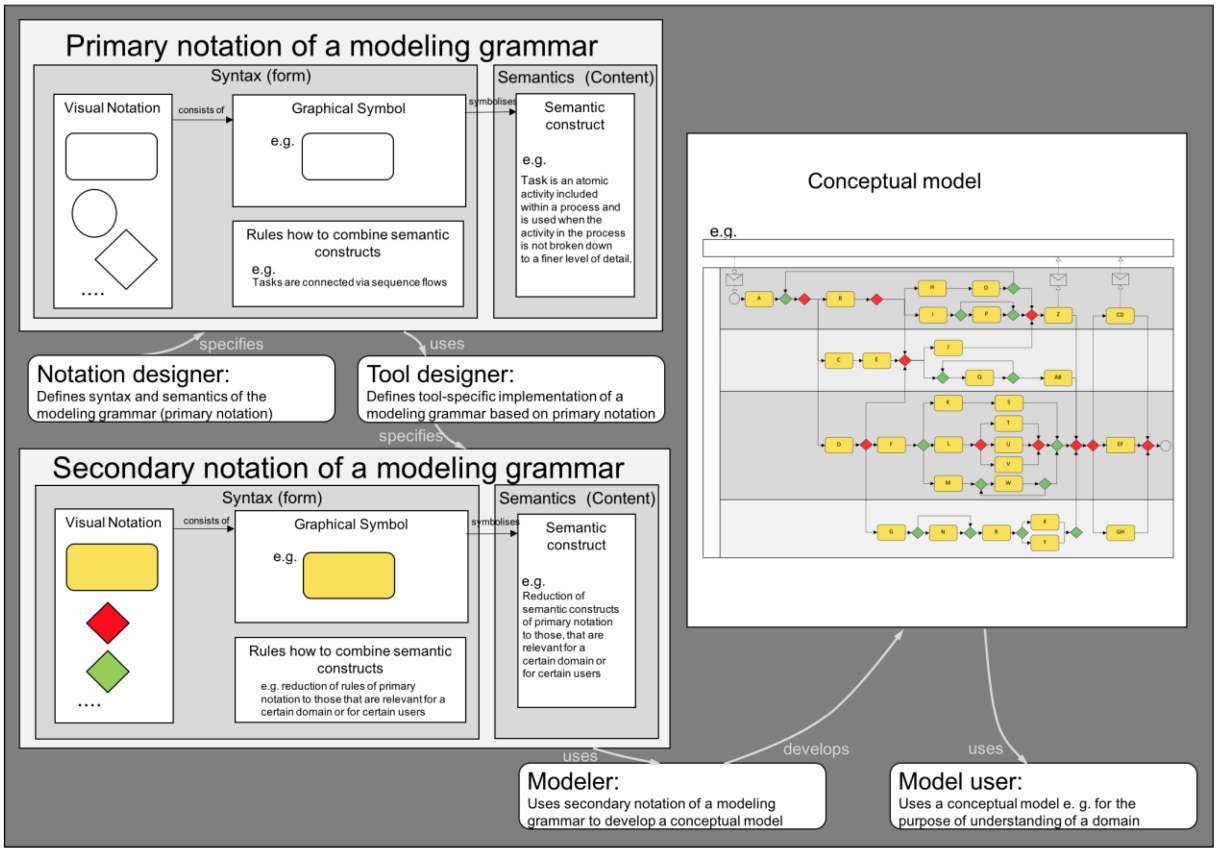

Fig. 1 Application of primary and secondary notation for a conceptual model and roles in conceptual modeling.

Yet, in most cases modelers use a modeling tool to develop their models and do that way not use the primary notations of a modeling grammar but are rather offered a tool-specific implementation (secondary notation). This implementation is usually based on the primary notation

and can further offer improvements that go beyond what is defined in primary notation such as visual cues [10] or restrictions such as reduced complexity for novice modelers [8].

Benefits, such as communication and shared understanding, that can be gained by using conceptual models, indicate that human understanding of conceptual models is relevant, as these models rather involve humans than machines [11]. Yet, understanding of models can be error-prone, if the model is not developed on an appropriate basis [12]. A conceptual model can be worth ten thousand words [13] if modeler, notation designer and tool designer understand how the human visual system receives information represented within the model and are that way, able to align the model as well as primary and secondary notation to the model user's needs. If this is not done, text can even outperform graphical representations such as conceptual models [13] and several problems can occur when using the model. That way, practitioners that are generally domain experts but method novices often have problems in understanding the process flow of Business Process Models (BPMs) [14]. Further sources of problems with the alignment of models and notations to the human visual system include the use of an appropriate modeling grammar for a specific task [15-16], the complexity which is treated within a conceptual model [8] and how information within different views of a model is connected [17].

Prior research of Conceptual Modeling has assessed theories of Cognition to develop solutions of how models and (primary as well as secondary) notations can be aligned to the model user's visual system and can thus, overcome some of these problems. STARK & ESSWEIN have summarized these solutions in [18]. Yet, most of these research solutions are not yet available in primary notation. [19] has identified two reasons for a missing integration of recent research solutions within primary notation. First, integrating recent solutions requires notation designers to review prior research before defining or updating primary notation. As these research results have recently not been available within a review paper [18] this has been very time-consuming which is why notation designers might refrain from this task. Second, an update of primary notations that are available as a standard, such as BPMN 2.0 which is available as Object Management Group (OMG)-Standard, requires to work on the grammar within a standardized procedure which is also very time-consuming [20]. Based on these two reasons modelers can usually not use those cognitive effective modeling grammars that are discussed in recent research papers [18].

Secondary notation, as a tool-specific implementation of primary notation [8], allows to quickly implement recent research solutions and thus, enables tool-designers to expand primary notation for those ideas that allow to design cognitive efficient models until primary notation has been worked on [19].

Secondary notation as an instrument to integrate recent research ideas has recently been under discussion [19]. That way, [8] argues that a lot of changes that are implemented in secondary notations (e. g. mechanisms for explicit complexity management) should rather be treated in primary notation. Furthermore, [21] argues that secondary notation should not contradict what is specified in primary notation and should that way, be treated very carefully. However, if primary notation is not contradicted and secondary notation is thus used very carefully, it can be argued that secondary notation might offer possibilities to exploit recent research results that are not yet available for secondary notation and thus, to allow the production of those cognitive effective models that are recently discussed in Conceptual Modeling such as in [4],[8],[21]. Moreover, an effective secondary notation might provoke a faster update of primary notation [19].

This dissertation aims to demonstrate how recent research solutions can be made available within secondary notation without contradicting primary notation and thus, allowing modelers to produce those cognitive efficient models that are discussed in prior research. For the de monstration of how recent research solutions can be made available in secondary notation, Perceptual Discriminability, as a limited research area, is selected and extended to a level, that an impact on model comprehension can be measured.

Perceptual Discriminability is defined in [8] and describes the ’ease and accuracy with which graphical elements can be differentiated from each other’ [8], p.763. Perceptual Discriminability can be determined by how much the visual variables (such as size, brightness and hue), that are used to encode the modeling constructs, differ for the modeling constructs used within the modeling grammar [22] and does hence, describe the visual distance between modeling constructs [8]. In the research field of Perceptual Discriminability MOODY argues that visual variables that are not used to encode semantic information should be used to redundantly encode information. This way, the visual distance between modeling constructs can further be increased [8] up to a point when construct seem to virtually pop-out from the rest of the model [4],[8]. Fig. 2. demonstrates the difference between modeling constructs that have a low and a high visual distance. For example, the entity types of Fig. 2b) only use the visual variables

that are defined to encode semantic constructs in [23]. On the contrary, Fig. 2a) also uses visual variables that are not used to encode semantic constructs but that are free to redundantly encode information. That way, in Fig. 2a) also brightness, hue und saturation are used as free variables to produce a visual distance that leads e. g. entity types pop-out from other constructs used in the model.

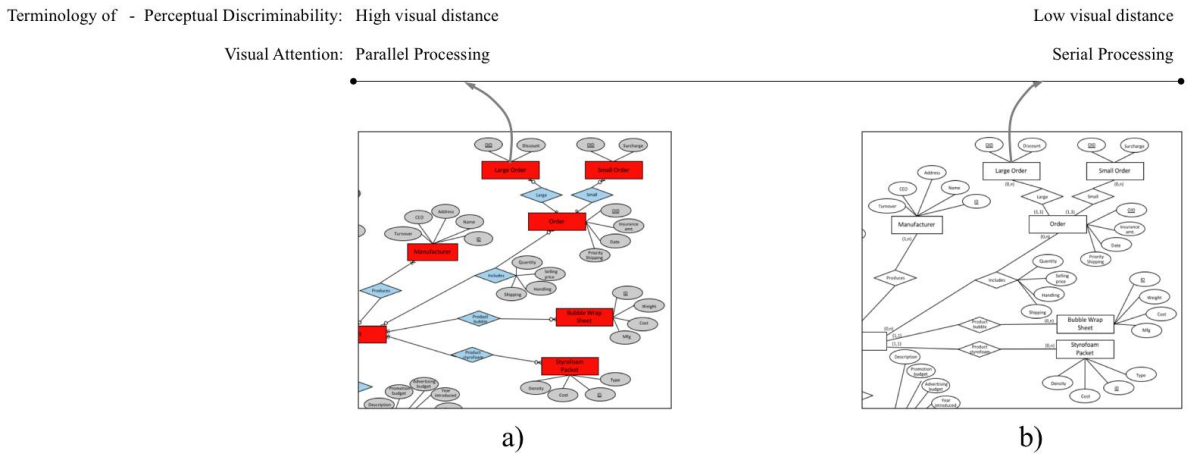

Fig. 2 Conceptual modeling constructs with a low (b) and a high visual distance (a) on the basis of [24].

The visual distance of a modeling construct has an influence on what information the model user sees with attention. That way, the model user's gaze is more likely to be drawn to the red entity types of Fig. 2a) than to the white entity types of Fig. 2b). Attention is crucial, as only information that is seen with attention and which is thus, selected for further processing in working memory, can be understood [25]. The research field of Visual Attention has defined a continuum between those two pols that are described as high and low visual distance in Perceptual Discriminability which they refer to as parallel and serial processing [25-26]. If the visual distance for an element is that high that a pop-out effect for this element is achieved, visual variables of this element are perceived in less than 200ms. In this case information can be processed very efficiently which is termed as parallel processing. If, on the other hand, an element is characterized with a low visual distance, attention will not be easily drawn to that element. In this case, this element is processed in serial [25]. Researchers of Visual Attention have also reached a consensus that these two states of parallel and serial processing are not rigid as first proclaimed in [27] but are rather pols of a continuum and that a position for elements along the continuum can be influenced [28-29].

How attention can be influenced within Conceptual Modeling has so far not been researched. Yet, influencing the modeler's attention reveals potential for (primary and secondary) notation designers, modelers as well as model users and can be used on the instance as well as on the type level (see Fig. 3). On the type level, primary notation designers can use extended Perceptual Discriminability to guide the model user's gaze to those modeling constructs that are important to comprehend the model itself. For Entity-relationship diagrams (ERDs), for example, a focus on entity-types can be very helpful as the model user usually needs to scan the whole model for those entity types that they require to solve the tasks they have used the model for [24]. Identifying those constructs that are important for model comprehension can help notation designers to improve the modeling grammar. If primary notation designers have not yet exploited this potential, designers of secondary notations can still do so and that way might provoke a change for primary notation. If this potential is used by primary or secondary notation designers, model comprehension for model users can be increased.

Tool designers can improve their modeling tool and increase its functionality. That way, they might allow modelers to influence the model user's gaze on the instance level by individually choosing values of visual variables for model elements that are important to understand the message of the model and thus, influence domain understanding. That way, those parts of the model that convey the most important message can be highlighted by working on the conditions of extended Perceptual Discriminability. If tool designers provide this functionality, modelers benefit as they can actively influence what is seen on the instance level und thus, influence what model user understand from the model. Extended Perceptual Discriminability can thus be used to improve the individual model on the instance level or to improve the modeling grammar or modeling tool on the type level, which then might also effect the instance level. While an improved model effects the model user's domain understanding as information presented in the model can be better understood, an improved modeling grammar might initially result to an improved model comprehension as the model user is enabled to better understand the modeling grammar [18].

To use this potential this dissertation aims to extend Perceptual Discriminability for conditions to influence the model user's attention and demonstrates its application for secondary notation.

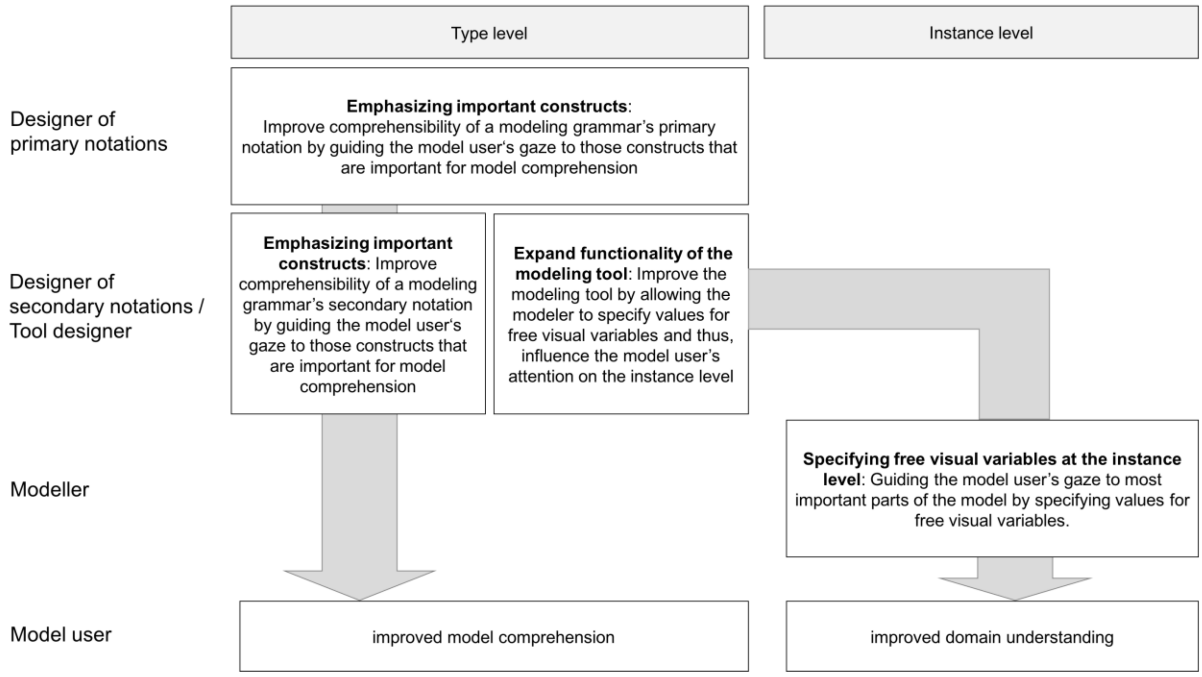

Fig. 3 Potential of extended Perceptual Discriminability for Conceptual Modeling.

2. Research design

For an explication of the research design this dissertation uses the reference framework of [30]. The author of this work takes an open-ontic position and admits that thinks are perceived subjectively. Furthermore, research results are obtained on the basis of consensus which implies that a statement is true if this statement can be rationally accepted by a research community [31]. On this basis research objectives are formulated in section 2.1, the scope of this dissertation is discussed in section 2.2 and the research methods that are used within this dissertation are presented in section 2.3.

2.1 Research objectives

The **overall research objective** of this dissertation is extending Perceptual Discriminability for influencing the model user's attention and to demonstrate how extended Perceptual Discriminability can be used to improve the cognitive effectiveness of secondary notations.

This overall research objective has its **basis** in a review of hypotheses for Conceptual Modeling that are drawn from Cognition in [18], which classifies dependent and independent variables of these hypotheses. Based on this review and an extension of these hypotheses in [32] the research gap is identified and research objectives are defined. Sub-objectives of the overall research objective are further developed that help structuring this dissertation.

The **first research objective** extends Perceptual Discriminability for conditions to influence the model user's attention. This extension comprises the basis for the advantages (summarized in Fig. 3) that can be gained by influencing the model user's gaze. Extended Perceptual Discriminability will first be applied to a specific question within Conceptual Modeling and the results will be evaluated within a laboratory experiment.

In this dissertation in most cases the modeling grammar BPMN is used for the demonstration as Business Process Models (BPMs) are increasingly used among practitioners [33],[2] and the BPMN has replaced multiple competing standards [21]. Attention cannot be drawn to every BPMN construct due to interferences from visual variables [24],[34]. These conditions should rather be used to draw the model user's attention to the most important constructs of a modeling grammar or to those parts that reveal the most important information. Constructs that are most important for BPMN model comprehension are researched within the **second research objective.**

Furthermore, free visual variables need to be specified and further worked on for BPMN constructs that are important for model comprehension. Visual variables that are used within the BPMN primary notation should not be contradicted and should that way not be changed within secondary notation [21]. The specification of BPMN visual variables that are free for BPMN secondary notation will be researched as the **third research objective**.

Those visual variables that are free for an application for secondary notation (outcome of research objective three) need to be worked on according to the conditions of how attention can be influenced (outcome of the first research objective). That way, for the **fourth research objective** free visual variables for BPMN secondary notations are researched in detail to further specify how conditions to influence the model user's attention for those visual variables can be met. A summary of these research objectives that are comprised within the overall research objective is given in Fig. 4.

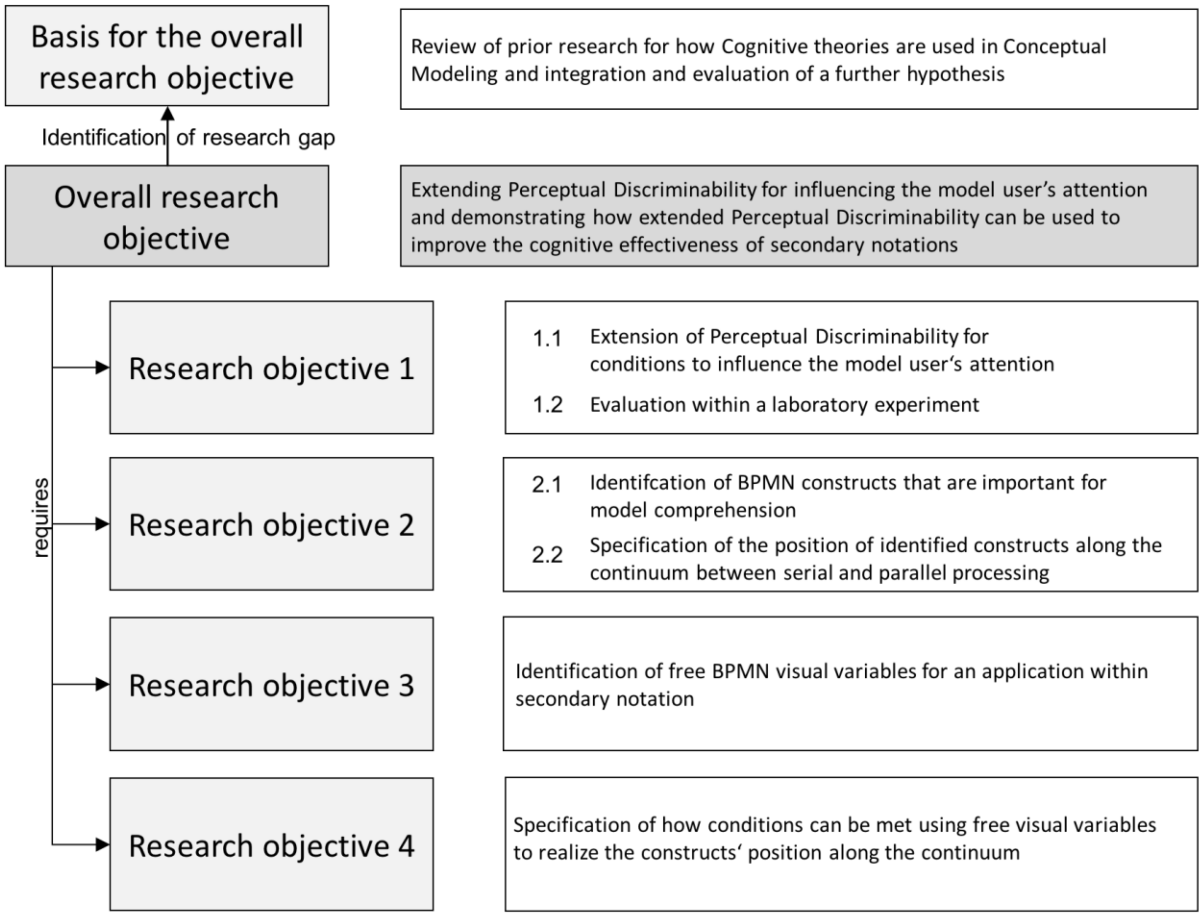

Fig. 4 Summary of research objectives.

2.2 Scope

Primary notations generally specify syntax and semantics of a modeling grammar [3],[35]. Syntax of modeling grammars defines graphical symbols (constructs) that are included within the grammar as well as a specification of how these constructs can be combined. Furthermore, graphical representations (visual or concrete syntax) are specified [36],[8]. Graphical symbols are used to perceptually represent (or symbolise) semantic constructs and are in general defined within a metamodel that specifies the semantic of those constructs [8]. By using Perceptual Discriminability for demonstrating how secondary notation can be used to integrate recent research solutions, this dissertation focusses on visual notations of modeling grammars and that way addresses the concrete syntax (see Fig. 5). Apart from answering the first research objective that also includes reviewing recent research solutions with a focus on semantics and syntax, this dissertation is limited to the concrete syntax of modeling grammars and does not contribute to semantics.

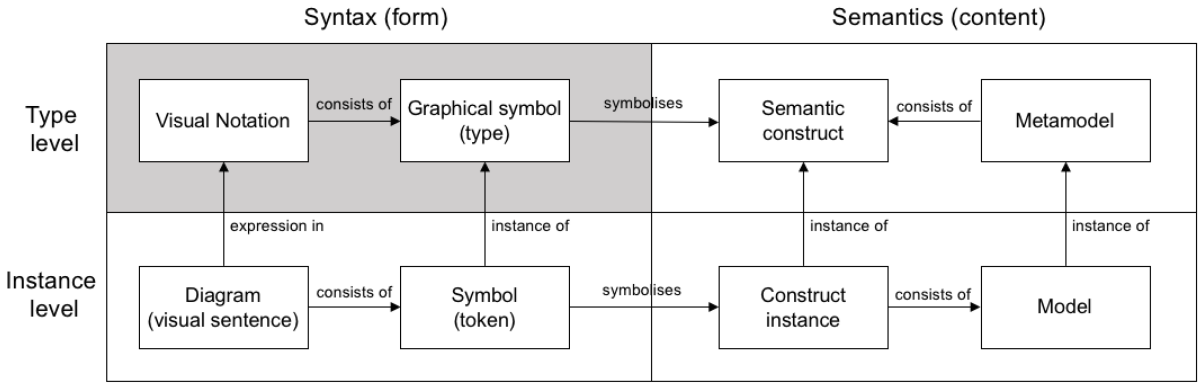

Fig. 5 Scope of this dissertation on the basis of [8], p. 757.

A second limitation of this dissertation concerns the discrimination between type and instance level as depicted in Fig. 5. As this dissertation discusses how extended Perceptual Discriminability can be used to improve modeling grammars, a clear focus lies on the type-level. That way, potentials of extended Perceptual Discriminability for the instance level such as the possibility to direct the model user's gaze to those parts of the model that reveals the most important information for domain understanding will not be focussed on (see Fig. 6). This work rather discusses how comprehension of modeling grammars can be increased with a focus on secondary notation. Although research results are not explicitly addressed to primary notation, most results can (and should) also be applied to primary notation.

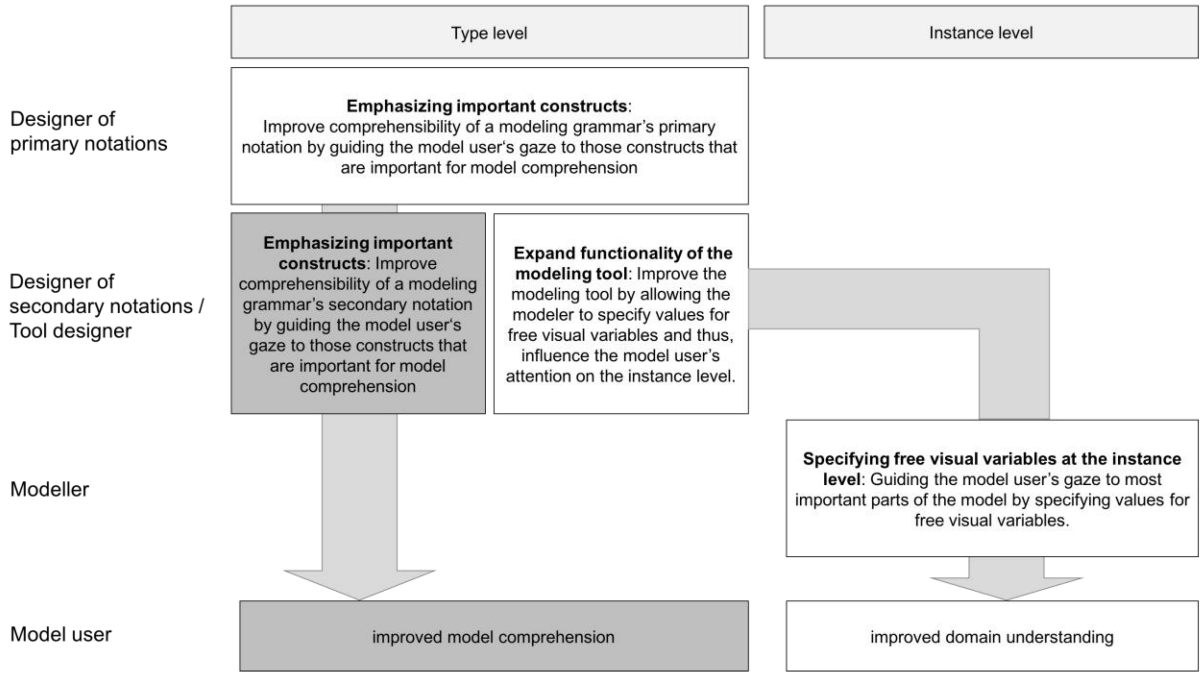

Fig. 6 Scope of this dissertation on the basis of potentials of extended Perceptual Discriminability.

As the scope of this dissertation is limited to the type-level this work follows a method-oriented research approach. The overall research objective comprises an extension of Perceptual Discriminability to influence the model user's attention and an integration of extended Perceptual Discriminability into BPMN secondary notation, which is why this dissertation aims on making BPMN secondary notation more cognitive effective, and thus aims on changing secondary notations of BPMN. To reach this goal, comprehension of how attention can be influenced is required. Yet, comprehension is not the main objective of this dissertation (see Fig. 7)

	Comprehend	Design / Change
Method-orientated research goals	-	Extending Perceptual Discriminability to influence the model user's attention and integration into BPMN secondary notation
Artifact-orientated research goals	-	-

Fig. 7 Positioning the overall research objective into the classification of [30].

2.3 Research method

This dissertation uses an argumentative-deductive approach as is discussed for information systems in [37-38] and which is used to analyze and extend existing literature and to build new groundwork. [38], p. 291-292 (in its original version) discusses literature analysis and library research as argumentative-deductive approaches. In library research past research is synthesized as well as important conclusions are highlighted and that way, a synapsis of a certain scientific area can be provided [38]. On the contrary, literature analysis examines (in most cases complete) past research of a particular area and that way, conducts a meta analysis of the cumulative knowledge and treats the individual studies as one data point [38-39].

To reach the overall research objective, results of several research areas have been analysed. Research results of Visual Attention have been used to extend Perceptual Discriminability (first research objective). Colour Theories and theories of Colour Harmony have been assessed and analysed to work on the conditions for influencing the model user's gaze using

visual variables that are free for BPMN secondary notation (fourth research objective). As the review of these research areas does not treat the studies as single data points this dissertation follows the approach of library research and that way, rather aims on providing a synapsis of research results of Visual Attention, Colour Theory as well as Colour Harmony that might reveal potential for Conceptual Modeling. Nonetheless, working on some research objectives also requires a more thorough method which also includes to treat individual studies as single data points. That way, for the basis of this research (identifying hypotheses that were drawn from Cognition for Conceptual Modeling) as well as for research objective two (identification of those constructs that are important for model comprehension) a more formal analysis of each study is required. As the research goal in this case is not to derive cumulative knowledge which is usually aimed for in literature analyses, but literature was assessed to answer very specific questions (e. g. summary of dependent as well as independent variables of hypotheses as well as importance of modeling constructs for model understanding) a content analysis according to [40] is selected for this task. This research method offers to systematically describe certain features of texts [41]. That way, dependent and independent variables of hypotheses are assessed to summarize hypotheses for Conceptual Modeling from Cognition and experiments within Conceptual Modeling are assessed for what questions can be solved with the modeling grammar.

For the evaluation of research outcomes this dissertation also includes laboratory experiments that follow the framework for empirical evaluations of conceptual modeling techniques discussed in [42] and that way, clearly address dependent, independent and affecting variables.

In this dissertation also the design science approach of [43] and an extension of [44] is used to derive harmonic colour combinations for Conceptual Modeling. Research methods used in this dissertation are summarized in Fig. 8.

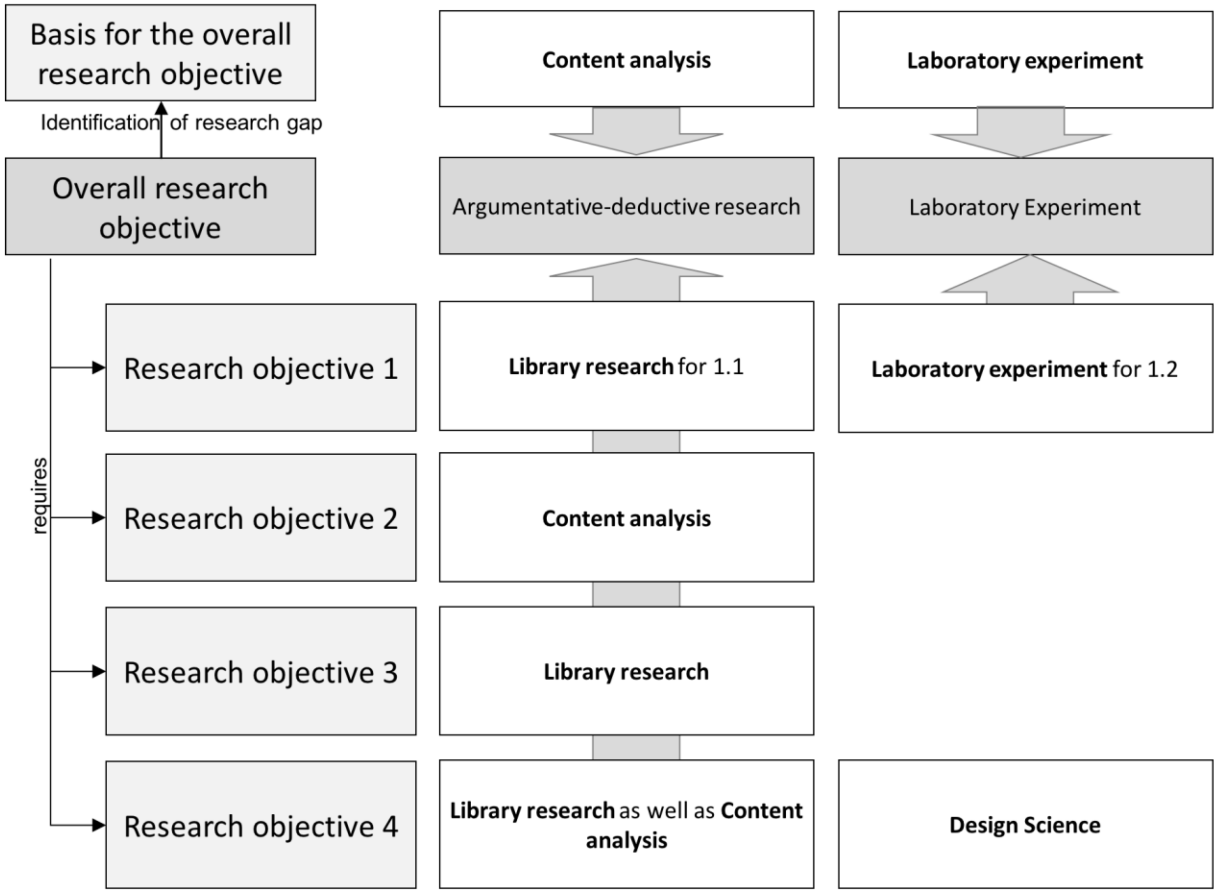

Fig. 8 Research methods used in this dissertation.

3. Structure of the dissertation

The dissertation is the result of a cumulative research process that comprises six publications which have been developed and published / submitted between 2012 and 2016. The individual publications contribute to the overall research objective of this dissertation as described in Fig. 9. The relations between the publications that form this dissertation are further summarized in Fig. 10.

The research gaps have been identified based on a review of hypotheses that have been discussed for Conceptual Modeling and that base on theories of Cognitions (publication 1). This dissertation comprises two research lines that extend identified hypotheses a) for the dependent variable modeling efficiency (publication 2) and b) for the dependent variable model model comprehension (publication 3-6). The extension of current hypotheses for modeling efficiency is only described and evaluated within one publication and is not further focussed on in this dissertation.

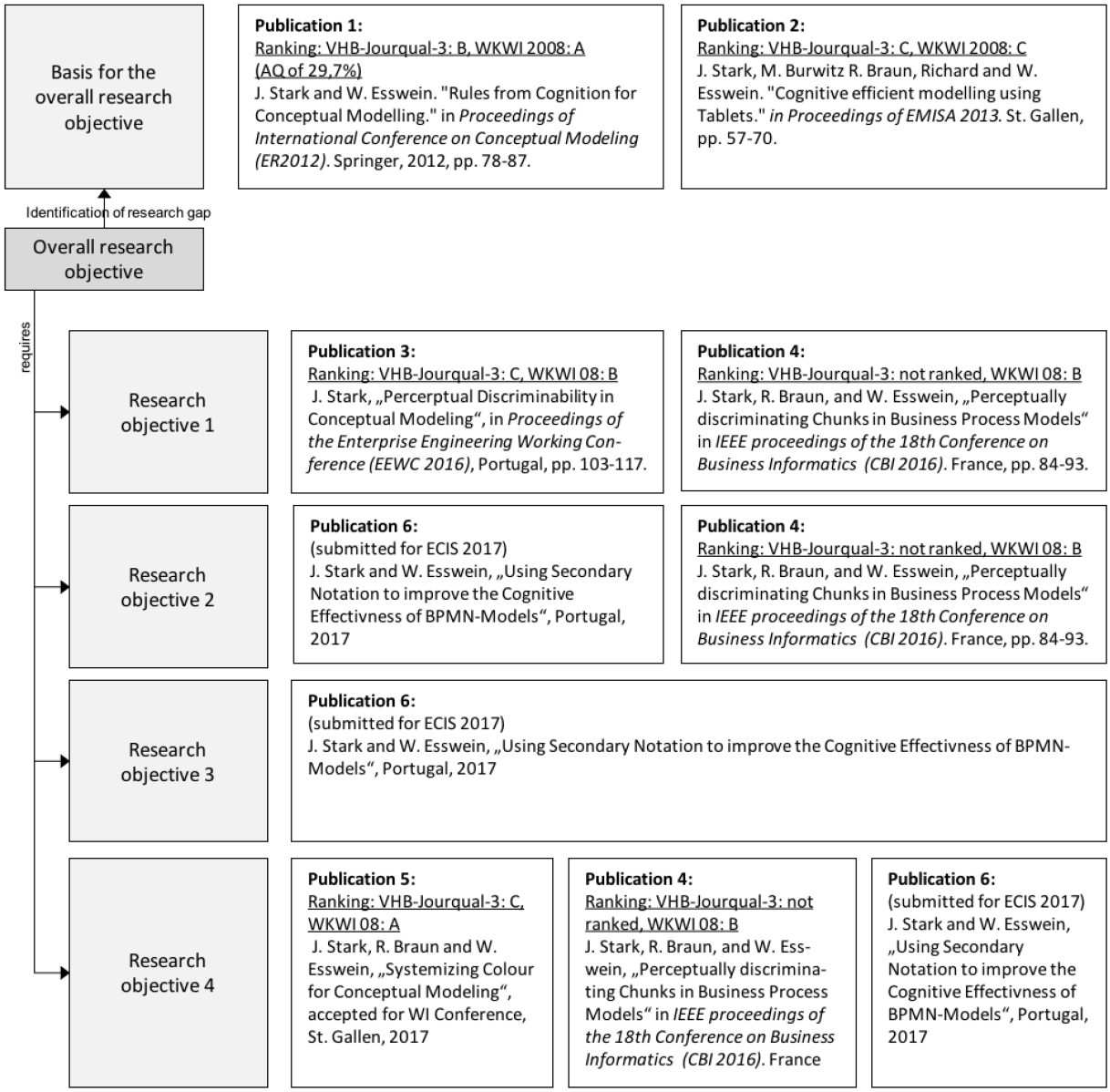

Fig. 9 Contribution of publication 1-6 to the research objectives.

The main contribution comprises the extension of hypotheses for model comprehension and deals with extending Perceptual Discriminability and its application for BPMN secondary notation. Perceptual Discriminability is extended in Publication 3 for the continuum between serial and parallel processing as well as for conditions of how elements can be placed alongside the continuum. In publication 4 extended Perceptual Discriminability is applied to the process flow of BPMs. For elements that are identified as most important to comprehend the process flow, visual variables have been optimized according to the conditions of extended Perceptual Discriminability of publication 3. The optimized process model is further evaluated with a laboratory experiment and that way, the influence possibilities of extended Per-

ceptual Discriminability on model comprehension are assessed. Moreover, publication 6 assesses the importance of further BPMN elements for model comprehension. Those elements that are decided to be most important for model comprehension are placed alongside the continuum in publication 4 and 6. As this work focusses on secondary notation, free BPMN visual variables for secondary notation are further discussed in publication 6. Conditions to influence the model user's attention are further specified for identified free visual variables, which comprise hue, saturation and brightness, in publication 5. Moreover, this publication provides harmonious colour combinations that can be used in Conceptual Modeling. Based on the specification of conditions for those free visual variables, the positions along the continuum are discussed and worked on for important BPMN chunks and constructs in publication 4 and 6. Publication 6 synthesizes research of this research line.

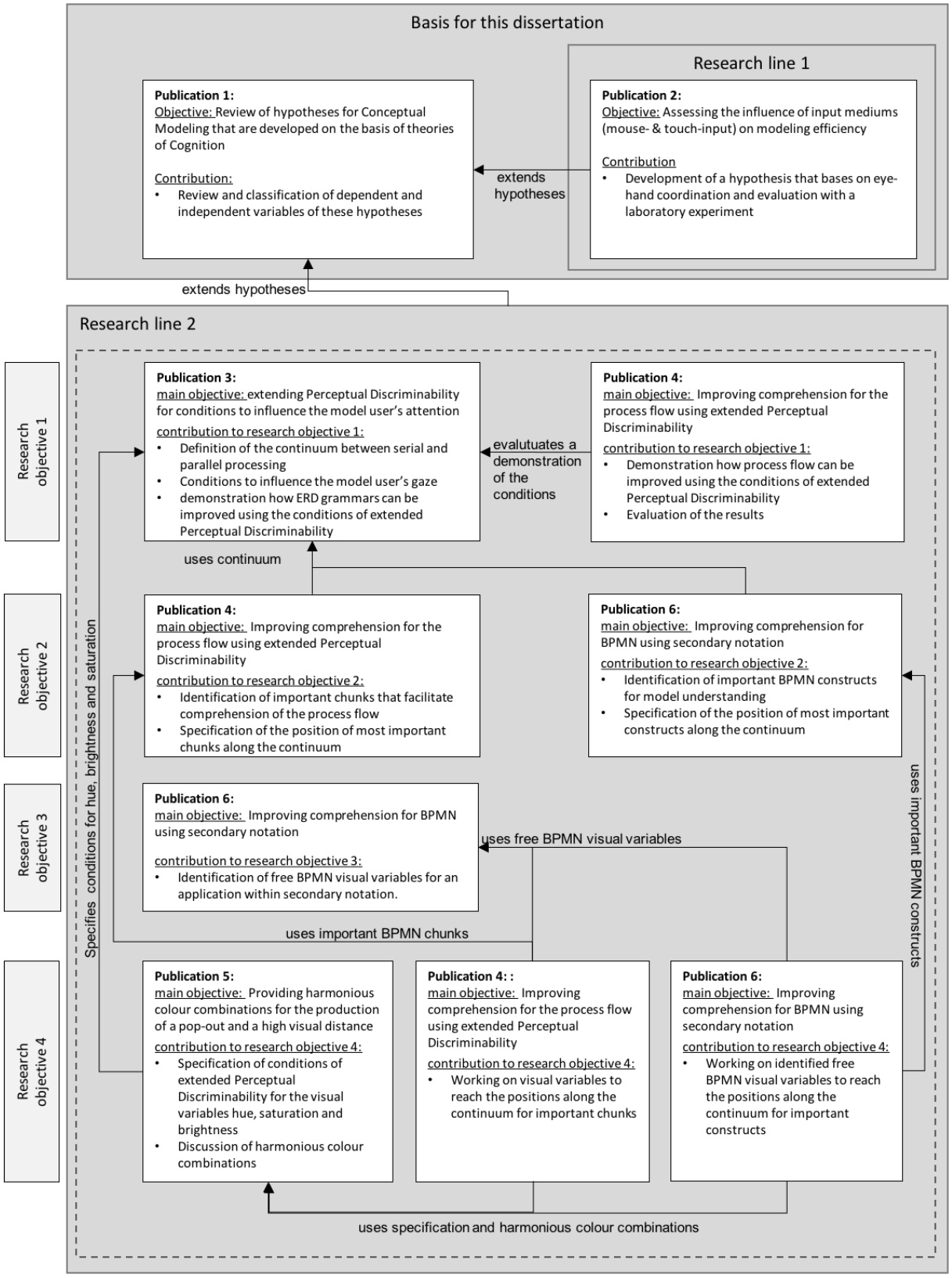

Fig. 10 Relation among publications of this dissertation.

4. Contribution to theory and practice

This research contributes to theory and practice as is summarized in Table 1. The basis for this dissertation, which comprises the review of hypotheses for Conceptual Modeling from Cognition, classifies independent and dependent variables. Researchers can use the classification of independent variables to further identify research gaps and the classification of dependent variables for a specification of dependent variables for their empirical research. Practitioners can use the review to improve the cognitive effectiveness and efficiency of models and modeling grammars as well as to improve modeling efficiency.

The first research line assesses the dependent variable modeling efficiency (publication 2) and contributes to research by developing and evaluating the hypothesis that eye-hand coordination has an influence on modeling efficiency that way, increases the cognitive foundations of modeling grammars.

The second research line extends Perceptual Discriminability and assesses its influence on the dependent variable model comprehension for secondary notation. For theory, this research line contributes an extension of theories for the concrete syntax of modeling grammars. Furthermore, a first systematization of colour for two conceptual modeling colour scenarios is developed and a hierarchy of important modeling elements for BPMN and ERD has been discussed and can further be used to include pragmatics for further improvements. For practice, results of extended Perceptual Discriminability can be used to improve the cognitive effectiveness of BPMN as well as of ERD secondary notation. Moreover, harmonious colour combinations are provided that tool designers can use for secondary notations.

Table 1 Contribution to theory and practice.

Publication	Contribution to theory	Contribution to practice
	Basis of this dissertation	
Publication 1	• Classification of independent variables can be used to further identify research gaps • Classification of dependent variables can be used for the specification of a dependent variable for empirical research	• Research results, that can be used to improve the cognitive effectiveness and efficiency of modeling grammars as well as modeling efficiency, are made available within one study
	Research line 1	
Publication 2	• Analysis and evaluation of the influence of eye-hand coordination on modeling efficiency	• Providing results from eye-hand coordination on touch-input and mouse-input that can be used by tool-designers to increase modeling efficiency
	Research line 2	
Publication 3	• Theory-extension of Perceptual Discriminability to influence the model user's attention • Identification of the most important ERD constructs for model comprehension	• Concrete ideas to improve model comprehension of ERDs
Publication 4	• Analysis and example of how model user process information of conceptual models • Identification of the most important BPMN chunks for process flow comprehension	• Concrete ideas to improve comprehension of BPM process flows
Publication 5	• Conceptual modeling colour scenarios are developed as the result of an analysis what colour is used for in Conceptual Modeling • Systematization of colour attributes for Conceptual Modeling for two conceptual modeling colour scenarios	• General guidelines for colour application within Conceptual Modeling are researched • Guidelines how specific conceptual modeling colour scenarios can be reached by using colour attributes • Provision of harmonious colour combinations that can be used for an optimization of secondary notations as well as to offer an increased tool functionality by choosing colour palettes for the individual models
Publication 6	• Identification of the most important BPMN constructs for model comprehension	• Process description how research results can be integrated into secondary notations • Concrete ideas to improve BPMN secondary notation based on extended Perceptual Discriminability

5. Future Research Ideas

For the basis of this dissertation an update of hypotheses for Conceptual Modeling that are defined on the basis of Cognition is required for dependent and independent variables. Furthermore, those hypotheses that are so far not empirically assessed, can be evaluated using laboratory experiments. Also the relations that are defined among dependent variables need a more thorough analysis as in this work relations are only defined on the basis of the studies used within the content analysis.

Research line 1 has extended the hypotheses identified within the review for the independent variable eye-hand coordination and dependent variable modeling efficiency. A further research idea comprises researching the influence of layout-algorithm on modeling efficiency.

For research line 2 an evaluation did so far only occur for process flow comprehension and the final results still not have been evaluated. Furthermore, extended Perceptual Discriminability has so far only been applied to the type-level. Yet, extended Perceptual Discriminability also reveals potential for the instance level as is described in Fig. 3. That way, researching how the model user's attention can be guided to those parts of the model that reveal the most important information for domain understanding are not researched yet. Results of this dissertation have only been used to improve model comprehension for ERD and BPMN but might also be applied to further modeling grammars. Further research ideas also comprise the specification of visual variables for the conditions of extended Perceptual Discriminability. That way, a specification of the visual variable shape is still required and might have an impact on improving primary notations. Furthermore, the interrelation between shape and orientation is still not researched and might reveal further potential.

Table 2 Future Research Ideas.

Research Line	Further Research Ideas
Basis	• Update of hypotheses (dependent and independent variables) • Evaluation of hypotheses that have not yet been empirically assessed • Relation between dependent variables are so far only derived from literature used within the content analysis which is why a more thorough analysis is required to assess relations between those variables
Research Line 1	• Assessing the influence of layout algorithm on modeling efficiency and model comprehension • Assessing how speech can increase tool functionality
Research Line 2	• Evaluation of research results of Publication 6 • Application of research results for further modeling grammars • Application of extended Perceptual Discriminability for the instance level • Specification of conditions for the visual variable shape • Research of the interrelation between shape and orientation

PART 2 - PUBLICATIONS

Publication 1

Title	Rules from Cognition for Conceptual Modeling		
Authors	Jeannette Stark Werner Esswein		
Publication	Jeannette Stark and Werner Esswein. 'Rules from Cognition for Conceptual Modeling' in *International Conference on Conceptual Modelling (ER 2012)*, Springer, 2012, pp. 78-87.		
Reference in this dissertation:	[18]		
Availability	http://link.springer.com/chapter/10.1007/978-3-642-34002-4_6		
Ranking	VBH-Jourqual-3: B WKWI 2008: A (Acceptance Quote: 29,7%)		
Contribution to the publication	Conception	Jeannette Stark	70%
		Werner Esswein	30%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	100%
	Formulation of the manuscript	Jeannette Stark	100%
	Proof of manuscript	Jeannette Stark	70%
		Werner Esswein	30%

Publication 2

Title	Cognitive efficient Modeling using Tablets		
Authors	Jeannette Stark Martin Burwitz Richard Braun Werner Esswein		
Publication	Jeannette Stark; Martin Burwitz; Richard Braun and Werner Esswein. "Cognitive efficient Modeling using Tablets." in *Proceedings of EMISA 2013, St. Gallen*. pp. 57-70.		
Reference used in this dissertation	[32]		
Availability	http://cs.emis.de/LNI/Proceedings/Proceedings222/57.pdf		
Ranking	VBH-Jourqual-3: C WKWI 2008: C		
Contribution to the publication	Conception	Jeannette Stark	70%
		Werner Esswein	30%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	50%
		Martin Burwitz	25%
		Richard Braun	25%
	Formulation of the manuscript	Jeannette Stark	80%
		Martin Burwitz	10%
		Richard Braun	10%
	Proof of manuscript	Jeannette Stark	70%
		Werner Esswein	30%

Publication 3

Title	Perceptual Discriminability in Conceptual Modeling		
Authors	Jeannette Stark		
Publication	Jeannette Stark. "Perceptual Discriminability in Conceptual Modeling" *Proceedings of the Enterprise Engineering Working Conference (EEWC2016)*. Funchal, pp. 103-117.		
Availability	http://link.springer.com/chapter/10.1007/978-3-319-39567-8_7		
Reference used in this dissertation	[24]		
Ranking	VBH-Jourqual-3: C WKWI 2008: B		
Contribution to the publication	Conception	Jeannette Stark	100%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	100%
	Formulation of the manuscript	Jeannette Stark	100%
	Proof of manuscript	Jeannette Stark	100%

Publication 4

Title	Perceptually discriminating Chunks in Business Process Models		
Authors	Jeannette Stark Richard Braun Werner Esswein		
Publication	Jeannette Stark, Richard Braun, Werner Esswein. 'Perceptually discriminating Chunks in Business Process Models', in *IEEE Proceedings of the 18th Conference on Business Informatics (CBI 2016)*, Paris, pp. 84-93.		
Availability	http://ieeexplore.ieee.org/abstract/document/7780303/?reload=true		
Reference used in this dissertation	[34]		
Ranking	VBH-Jourqual-3: not ranked WKWI 2008: B		
Contribution to the publication	Conception	Jeannette Stark	70%
		Richard Braun	15%
		Werner Esswein	15%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	100%
	Formulation of the manuscript	Jeannette Stark	80%
		Richard Braun	20%
	Proof of manuscript	Jeannette Stark	80%
		Richard Braun	20%

Publication 5

Title	Systemizing Colour for Conceptual Modeling		
Authors	Jeannette Stark Richard Braun Werner Esswein		
Publication	Jeannette Stark, Richard Braun and Werner Esswein. 'Systemizing Colour for Conceptual Modeling', in *AIS Proceedings of Wirtschaftsinformatik Conference (WI 2017)*, St. Gallen.		
Availability	http://aisel.aisnet.org/wi2017/track03/paper/2/		
Ranking	VBH-Jourqual-3: C WKWI 2008: A		
Reference used in this dissertation	[45]		
Contribution to the publication	Conception	Jeannette Stark	80%
		Richard Braun	10%
		Werner Esswein	10%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	100%
	Formulation of the manuscript	Jeannette Stark	90%
		Richard Braun	10%
	Proof of manuscript	Jeannette Stark	90%
		Richard Braun	10%

Publication 6

Title	Using secondary notation to improve the cognitive effectiveness of BPMN-Models		
Authors	Jeannette Stark Werner Esswein		
Publication	Jeannette Starkand Werner Esswein. Using secondary notation to improve the cognitive effectiveness of BPMN-Models', in *Proceedings of European Conference on Information systems (ECIS 2017)*, Portugal. (in press)		
Availability	http://aisel.aisnet.org/ecis2017_rp/35/		
Reference used in this dissertation	[19]		
Ranking	VBH-Jourqual-3: B WKWI 2008: A		
Contribution to the publication	Conception	Jeannette Stark	80%
		Werner Esswein	20%
	State of the art	Jeannette Stark	100%
	Method	Jeannette Stark	100%
	Formulation of the manuscript	Jeannette Stark	100%
		Jeannette Stark	100%
	Proof of manuscript	Jeannette Stark	80%
		Werner Esswein	20%

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PART 3 - APPENDIX

Table 3 Experiment procedure for experimenters, publication 2.

Kurze Einführung in den Ablauf des Experiments (ca. 5 Minuten)

- Kurze Begrüßung
- Aufforderung den Experimentablauf für Probanden zu lesen
- Lesezeit ca. 4-5 Minuten

Schulungsbeispiel (ca. 25 Minuten)

- Öffnen der .etz im Cubetto
- Fragen, ob alle die gleiche Ausgangsbasis haben
- Hinweis, dass das Schulungsmodell inkl. Legende aufgeschlagen werden soll und gemeinsam modelliert wird
- Dabei:
    - Hinweis, dass mit Doppelklicken oder einmal Klicken auf Konstrukt Informationen zugefügt werden können
    - Hinweis zum Knicken von Kanten
    - Hinweis zum Zoomen

Story	Modellierung
• **Organisatorische Trennung: Bestellung (Kunde), Verkauf (Pizzabäcker, Lieferjunge)**	
• **Zunächst: Betrachtung der Kunden-Seite**	
1. Kunde stellt Hunger fest	• Ereignis
2. Kunde sucht sich eine Pizza aus	• Aktivität • Sequenzfluss vom Ereignis
3. Kunde bestellt die Pizza (Nachricht an Lieferanten)	• Aktivität, Typ: Senden • Sequenzfluss
4. Nun können zwei verschiedene Ereignisse eintreten, auf die unterschiedlich reagiert wird:	• Gateway, Typ: Ereignis-basiert • Sequenzfluss
5. Kunde erhält Pizza	• Ereignis • Sequenzfluss
a. Kunde bezahlt Pizza	• Aktivität • Sequenzfluss
b. Kunde verzehrt Pizza (manueller Vorgang)	• Aktivität, Typ: Manuell • Sequenzfluss
c. Der Hunger ist gestillt	• Ereignis • Sequenzfluss
6. es sind 60 Minuten vergangen	• Ereignis, Typ: Zeit • Sequenzfluss
a. Kunde fragt beim Pizzadienst nach	• Aktivität • Sequenzfluss
b. Kunde erhält Pizza	• Ereignis • Sequenzfluss
7. danach weiter wie unter 5.	• Sequenzfluss zu „Pizza bezahlen“
• **Betrachtung der Lieferanten-Seite nur als Blackbox**	• Pool (zusammengeklappt) „Verkauf“
• **Jetzt: Nachrichtenaustausch zwischen Beteiligten**	

8. Bestellung	• Nachricht • Nachrichtenfluss: „Pizza bestellen“ → Pool „Verkauf“
9. Pizza	• Ereignis „Pizza erhalten“ (2x), Typ: Nachricht • Nachricht • Nachrichtenfluss: Pool „Verkauf“ → „Pizza erhalten“ (2x)
10. Kassenzettel	• Nachricht, initiierend: ja • Nachrichtenfluss: Pool „Verkauf“ → „Pizza bezahlen“
11. Geld	• Nachricht, initiierend: nein • Nachrichtenfluss: „Pizza bezahlen“ → Pool „Verkauf“
12. Beim Pizzadienst nachfragen	• Nachrichtenfluss: „Beim Pizzadienst nachfragen“ → Pool „Verkauf“
13. Verantwortlichkeiten	• Schwimmbahn „Kunde“ • Pool „Bestellung“

Experimentdurchführung

- Schließen des Programms und neu importieren
- Ausgabe des Experimentmodells und der Legende
- Hinweis, dass die Bearbeitungszeit jetzt anfängt.
- Vorzeitiges Fertigwerden notieren
- Nach 15 Minuten Experiment beenden und .etz mit Nachname_vorname.etz benennen
- .etz auf Stick speichern und per email schicken

Posttest (ca. 3 Minuten)

- Post Test austeilen (auch individuell schon früher) und ausfüllen lassen

Table 4 Experiment procedure for probands, publication 2.

Kurze Einführung in den Ablauf des Experiments

Experimentaufgabe

Bitte bilden Sie das Modell in Ihrer Werkzeugumgebung nach. Achten Sie bitte bei Ihrer Modellnachbildung darauf, das Modell so genau wie möglich abzubilden. Bitte arbeiten Sie zügig, ohne sich dabei jedoch unter Stress zu setzen.

Wenn Sie die Nachbildung beendet haben, geben Sie uns bitte kurz durch Handheben bescheid.

Wenden Sie sich bitte an uns, wenn Sie Fragen haben, bzw. Modellelemente nicht finden.

Experimentmaterialien

Für die Nachbildung stehen Ihnen zum einen das Originalmodell und zum anderen eine Legende für die benötigten Konstrukte zur Verfügung.

Schulungsbeispiel

Das Experiment wird anhand des Beispiels „Pizzabestellen“ mit Ihnen durchgespielt. Dabei erhalten Sie Erklärungen zur Modellierungssprache BPMN und zur Anwendung der Sprache in Ihrem Werkzeug. Bitte stellen Sie mögliche Fragen sofort. Wenn Sie bei der Modellierung Schwierigkeiten haben, melden Sie sich bitte.

Experimentdurchführung

Sie bekommen jetzt ein neues Modell inkl. Legende. Bitte bilden Sie das Modell in Ihrem Werkzeug nach. Bleiben Sie dabei bitte so nah wie möglich am Modell.

Posttest

Sie bekommen nun ein Formular ausgehändigt mit Fragen zum Experiment. Bitte füllen Sie diesen aus.

Table 5 Pretest, publication 2

1. Haben Sie schon einmal Prozessmodelle erstellt?	Ja ☐	Nein ☐
2. Haben Sie schon einmal BPMN-Modelle erstellt?	Ja ☐	Nein ☐
3. Schätzen Sie bitte hier ihre Vertrautheit mit der BPMN auf einer Skala von 0-7 (0= absolut unvertraut, 7=sehr vertraut)	_____	
4. Haben Sie schon einmal Prozessmodelle genutzt?	Ja ☐	Nein ☐
5. Haben Sie schon einmal BPMN-Modelle genutzt?	Ja ☐	Nein ☐
6. Haben Sie schon einmal mit einem Modellierungstool gearbeitet?	Ja ☐	Nein ☐
7. Wenn Sie unter 6. ja angekreuzt haben, geben Sie bitte den Namen des/der Modellierungstools an.	_____ _____ ☐Weiß ich nicht	
8. Falls sie schon mit dem Cubetto Toolset gearbeitet haben, geben Sie bitte Ihre Vertrautheit mit dem Modellierungstool auf einer Skala von 0-7 an.	_____	
9. Falls Sie schon mit dem bizagi Process Modeler gearbeitet haben, geben Sie bitte Ihre Vertrautheit mit dem Modellierungstool auf einer Skala von 0-7 an.	_____	
10. Haben Sie schon einmal auf einem Tablet gearbeitet?	Ja ☐	Nein ☐
11. Wenn Sie unter 10. ja angekreuzt haben, geben Sie bitte an, welches Tablet sie verwendet haben?	_____ _____ ☐Weiß ich nicht	
12. Falls Sie schon mit einem Tablet gearbeitet haben, geben Sie bitte Ihre Vertrautheit mit dessen Handling und Bedienung auf einer Skala von 0-7 an!	_____	

Table 6 Posttest iPad-Version, publication 2.

1. Name:	
2. Geschlecht:	
3. Alter:	

4. Ich denke es war einfach für mich das Modell mit dem ipad zu erstellen. (Auf eine Skala von 0-7 gemessen; 0 – stimmt überhaupt nicht, 7 – stimmt genau)	
5. Ich denke die Modellerstellung mit dem ipad ist generell einfach. (Skala von 0-7)	
6. Das Lernen, wie man mit dem ipad Modelle erstellt, war einfach für mich. (Skala von 0-7)	
7. Das Lernen, wie man BPMN-Modelle erstellt, war einfach für mich. (Skala von 0-7)	
8. Die gegebene Zeit war für die Modellerstellung angemessen. (Skala von 0-7)	
9. Das Experiment war für mich sehr stressig. (Skala von 0-7)	
10. Die Namen der Elemente haben mich sehr verwirrt. (Skala von 0-7)	
11. Bei der Texteingabe hatte ich Probleme. (Skala von 0-7)	
12. Bitte nutzen Sie nachfolgenden Platz für allgemeine Hinweise und Kommentare:	

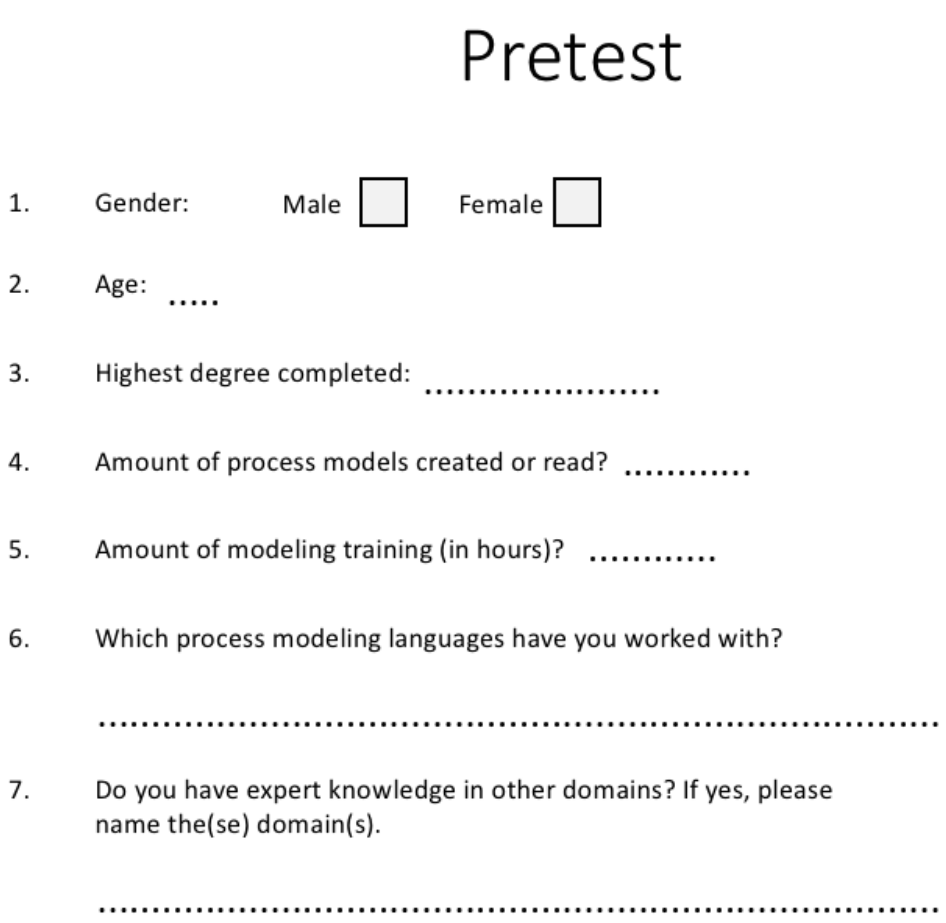

Fig. 11 Pretest for the experiment of publication 4.

Questions

Time required:.....

		Correct	Wrong
1.	C and K can be executed at the same point of time.	☐	☐
2.	G and O can be executed at the same point of time.	☐	☐
3.	E and N can be executed in parallel.	☐	☐
4.	H and M can be executed in parallel.	☐	☐
5.	In one process instance O as well as R can be executed.	☐	☐
6.	In one process instance A as well as P can be executed.	☐	☐
7.	The process steps S and P are mutually exclusive.	☐	☐
8.	The process steps B and J are mutually exclusive.	☐	☐
9.	A can be executed more often than F.	☐	☐
10.	F can be executed more often than Q.	☐	☐
11.	In any possible process instance Q is executed exactly as often as T.	☐	☐
12.	In any possbile process instance J is executed exactly as often as A.	☐	☐
13.	A and J are optionally executed within a process instance.	☐	☐
14.	The process step U is optionally executed within a process instance.	☐	☐
15.	While N is always executed, Q does not need to be executed.	☐	☐
16.	While J is always executed, U does not need to be executed	☐	☐

Fig. 12 Questions for the experiment of publication 4.

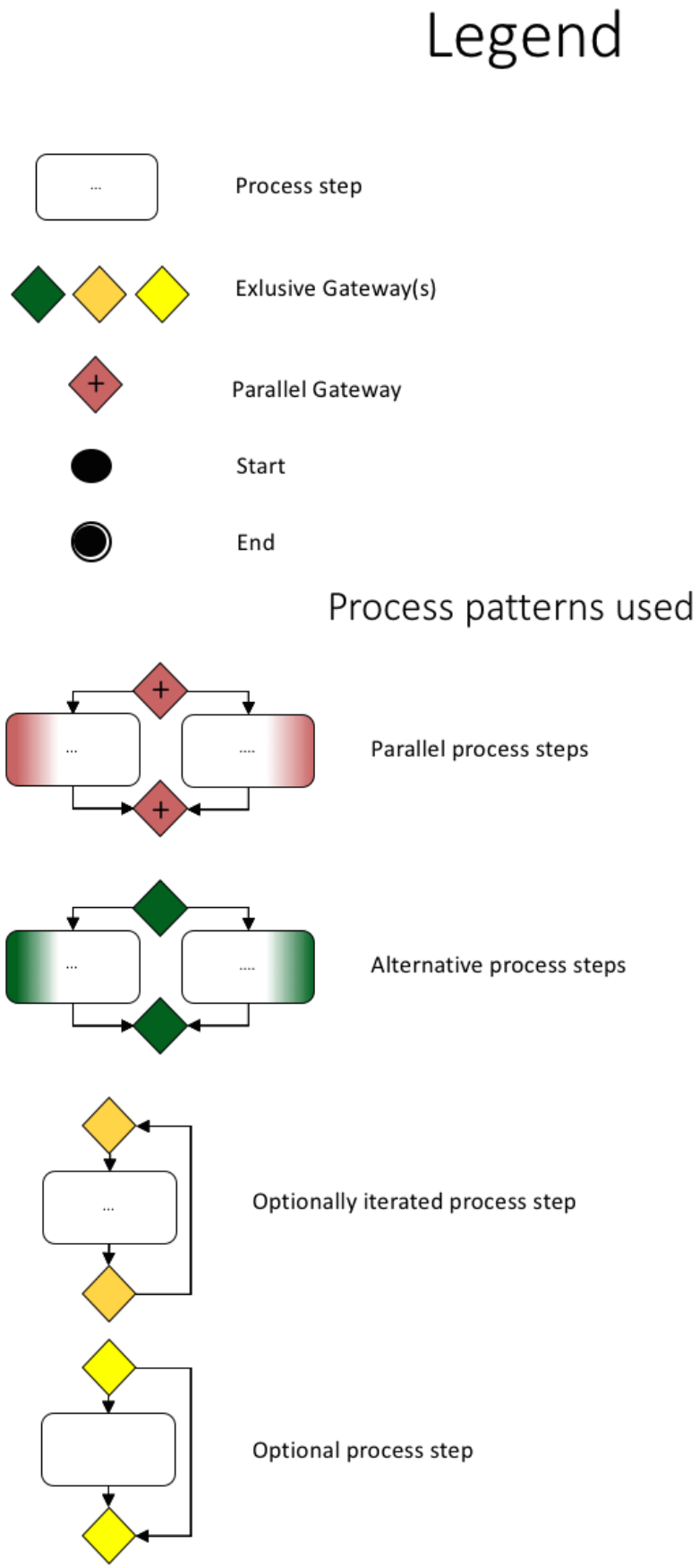

Fig. 13 Legend of the experiment of publication 4.

Post-Test

1. Did you have any problems with the Questions? If yes, please specify your problems below:

   .....

   .....

   .....

   .....

   .....

2. Did you have any problems with the language? .....

3. Please rate your confidence to have choosen the right answers on a scale from 1-7

   (1-low confidence, 7 high confidence) .....

4. Further remarks:

   .....

   .....

   .....

   .....

Fig. 14 Post-Test of the experiment of publication 4.