Cognitive Effectiveness in Conceptual Modeling

Kumulative

Habilitationsschrift

zur Erlangung der Lehrbefugnis (venia docendi)

für das Fach Wirtschaftsinformatik

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Contents

1 Abstract

Not even the most brilliant conceptual model would be of any use if no one could understand it. A basic precondition for a model's usefulness in practice is that it be comprehensible. With my research for this habilitation thesis, I contribute novel theoretical insights to the vibrant stream of cognitive research on conceptual modeling and provide empirical evidence on how to develop useful and understandable (visual) conceptual models. In my theoretical analyses, experiments and questionnaire-based studies, I investigated how best to exploit conceptual modeling as a cognitive tool for users in four modeling domains: business process modeling, business decision modeling, software feature modeling and instructional design modeling.

I have published my research findings in three of the eleven highest-impact information systems journals (Everard, St. Pierre and Heck, 2017) as a first author: *Journal of the Association for Information Systems (JAIS)*, *Decision Support Systems (DSS)* and *Information & Management (I&M)*. In addition, my sole-authored state-of-the-art article, "Comprehension of Procedural Visual Business Process Models – A Literature Review," appeared in the journal *Business & Information Systems Engineering (BISE)*. Other journal articles (in, e.g., *Information and Software Technology*, *International Journal of Human-Computer Studies, Journal of Visual Languages and Computing, Requirements Engineering)* and presentations at renowned international conferences (e.g., *Conference on Advanced Information Systems Engineering (CAISE), International Conference on Conceptual Modeling (ER), European Conference on Information Systems (ECIS)*) complete the habilitation thesis.

2 Introduction and Overview

The core of this habilitation thesis is a compilation of scientific articles that contribute to our understanding of human cognition in the context of conceptual modeling and our ability to design conceptual models that are optimized for human understanding and problem-solving. The complexity of contemporary information systems draws our attention to how appropriate methods and tools can support their design and analysis. Much of this attention has focused on techniques that support the modeling of information systems' requirements in terms of data or processes (Parsons, 2002). Conceptual models are instrumental in defining such requirements, as they support the analysis, design, development, and documentation of information systems. Because many errors in information systems can be traced to conceptual issues that stem from the requirements phase, and low-quality requirements models tend to make system development less efficient and less effective, many visual modeling notations have been developed to support communication among project participants in information system development. While the syntax and semantics of most conceptual modeling notations are well defined, humans' understanding of and ability to interact with such models have seldom been approached in a scientific manner. Although conceptual models are used to promote human understanding of a domain, practice shows that the ability to understand complex models soon reaches cognitive limits. In my habilitation, I studied a variety of open research questions and identified influence factors for cognitive effectiveness in conceptual modeling. Better understandability of conceptual models has direct significance for information systems development and will improve the requirements engineering process by facilitating a common understanding between users and system engineers.

This habilitation thesis makes significant theoretical and empirical contributions to six areas of human interaction with conceptual models:

- cognitive load theory and comprehension of conceptual models
- deductive reasoning and computational thinking with conceptual models (e.g., comprehension of control flow structures like sequence, loops, concurrency, and exclusiveness in process models; comprehension of OR/XOR relationships, constraints and optional/mandatory elements in software feature models)
- individual cognitive aspects of conceptual modeling (novice-expert differences, cognitive style, creative competence)
- the influence of the design of primary (e.g., semiotic clarity, perceptual discriminability, semantic transparency) and secondary (e.g., visualization, modeling style, layout strategies) modeling notation on model comprehension, user acceptance, user preference, and modeling errors
- evaluation, quality assurance and choice of modeling notations
- the effect of conceptual models on creativity in (business process) redesign tasks

Although general principles may apply to all conceptual models, frameworks for the quality of the various types of models (e.g., data models, process models) are needed because of fundamental differences among the types of models (Moody, 2005). While many of my research insights address universal principles that can be generalized to the parent class of conceptual models, I focused on exploring research gaps in four modeling domains: business process models, business decision models, software feature models, and instructional design models:

- **Business process modeling notations**: Business Process Model and Notation (BPMN) (Object Management Group, 2011), UML Activity Diagrams (UML AD) (Object Management Group, 2015b), Yet Another Workflow Language (YAWL) (van der Aalst and ter Hofstede, 2005), Event-driven Process Chains (EPCs) (Scheer, 2000)
- **Business decision model and notation** (DMN) (Object Management Group, 2015a)
- **Software feature / variability modeling notations**: Common Variability Language (CVL) (Haugen, 2012), Orthogonal Variability Model (OVM) (Pohl, Böckle and van der Linden, 2005)
- **Instructional design notations**: Educational Environment Modeling Language (E^2ML) (Botturi, 2006), Perspective-oriented Educational Modeling Language (PoEML) (Caeiro-Rodríguez, 2008), Cooperative Unified Modeling Language (coUML) (Derntl and Motschnig-Pitrik, 2008)

The remainder of this habilitation summary provides an overview of the publications that form the cumulative habilitation thesis. The work is structured as follows: Section 3 begins with an overview of the formal habilitation requirements of the Department of Information Systems and Operations' habilitation guidelines. Section 4 provides a theoretical background on cognitive load in human interaction with conceptual modes. Sections 5–10 present the major research contributions of the journal articles and conference papers. The articles and papers are ordered according to the type of independent variable investigated, as presented in section 4 and depicted in Figure 1. (A systematic categorization of articles according to the independent variables they investigated and dependent variables they measured is given in Table 5 in the Appendix's section A.)

A major goal of this document is to provide readers with an overview of the research questions addressed in my habilitation thesis and the theoretical and empirical contribution of the experiments and studies and how they relate to each other. This summary, then, does not represent new, stand-alone scholarly work, as it uses text from the articles that form the core of the habilitation. (For readability purposes, no direct quotations are used for these parts of the text; instead, references to the corresponding articles are highlighted in each section.)

3 Habilitation Requirements and their Fulfillment

The following sections give an overview of the habilitation guidelines of the Department of Information Systems and Operations at the Vienna University of Economics and Business (which are reproduced in the Appendix's section C) and describe how they are fulfilled by the publications that are submitted for the habilitation.

3.1 Habilitation Requirement 1

The minimum requirement for completing habilitation are five publications in very good journals. Very good journals are listed in the department's journal list (replicated in Table 6 in the Appendix's section B):

> Für eine Sammelhabilitation werden mindestens fünf thematisch zusammenhängende sehr gute wissenschaftliche Beiträge erwartet, die in sehr guten wissenschaftlichen Publikationsorganen (siehe unten) publiziert wurden…. Die Liste der für sehr gut eingestuften Zeitschriften des Departments für Informationsverarbeitung und Prozessmanagement bildet eine Grundlage für entsprechende Publikationsorgane (Positiv-Liste). (See habilitation guideline in the Appendix's section C, pp. 62-63.)

I fulfilled this requirement by publishing seven articles in seven journals in the department's journal list, in six of which I was the first author:

1. *Business & Information Systems Engineering (BISE)*
2. *Information and Software Technology (IST)*
3. *Information & Management (I&M)*
4. *Requirements Engineering (RE)*
5. *International Journal of Human-Computer Studies (IJHCS)*
6. *Decision Support Systems (DSS)*
7. *Journal of the Association for Information Systems (JAIS)*

Three of the articles in which I was first author were published in three out of the eleven highest-impact information systems journals: *Journal of the Association for Information Systems*, *Decision Support Systems* and *Information & Management*. Of the authors who have been published in any of these high-impact journals, only 18 percent have been published in them more than twice (Everard, St. Pierre and Heck, 2017).

Table 1 lists the references for the seven articles and the details about the ratings of the journals in which they were published. The journals are also marked in the department's journal list that is replicated in Table 6 in the Appendix's section B.

Table 1. Seven Articles Published in Journals Listed in the Department's Journal List [Habilitation Requirements 1 and 2][1]

Reference	Full Reference	VHB-JQ3	ABCD	WI-List	IF
(Sole-Authored) Journal Article 1 (Figl, 2017a)	Figl, Kathrin (2017). Comprehension of Procedural Visual Business Process Models. **Business & Information Systems Engineering**, 59(1), 41-67 **[Habilitation Requirement 2]**	B	A	A	2.06
Journal Article 2 (Reinhartz-Berger, Figl and Haugen, 2017)	Reinhartz-Berger, I., Figl, Kathrin, & Haugen, Ø. (2017). Investigating Styles in Variability Modeling: Hierarchical vs. Constrained Styles. **Information and Software Technology**, 87, 81-102.	-	A	-	1.57
Journal Article 3 (Figl and Recker, 2016a)	Figl, Kathrin, & Recker, J. (2016). Exploring Cognitive Style and Task-Specific Preferences for Process Representations. **Requirements Engineering**, 21(1), 63-85.	-	-	-	1.15
Journal Article 4 (Figl and Recker, 2016b)	Figl, Kathrin, & Recker, J. (2016). Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams. **Information & Management**, 53(6), 767–786.	B	A*	A	2.16
Journal Article 5 (Figl and Laue, 2015)	Figl, Kathrin, & Laue, R. (2015). Influence Factors for Local Comprehensibility of Process Models. **International Journal of Human-Computer Studies**, 82, 96-110.	-	B	B	1.48
Journal Article 6 (Figl, Mendling and Strembeck, 2013)	Figl, Kathrin, Mendling, J., & Strembeck, M. (2013). The Influence of Notational Deficiencies on Process Model Comprehension. **Journal of the Association for Information Systems**, 14(6), 312-338.	A	A*	A	1.79
Journal Article 7 (Figl, Recker and Mendling, 2013)	Figl, Kathrin, Recker, J., & Mendling, J. (2013). A Study on the Effects of Routing Symbol Design on Process Model Comprehension. **Decision Support Systems**, 54(2), 1104-1118.	B	A*	A	2.60

3.2 Habilitation Requirement 2

A second requirement of the habilitation guideline is that at least one article be a sole-authored article:

> Mindestens ein Journalbeitrag sollte daher als Alleinautor publiziert werden. (See habilitation guideline in the Appendix's section C, p. 63.)

[1] Explanation of table columns:

- **VHB-JQ3** – Ranking based on German Academic Association for Business Research (VHB) - Jourqual 3 (2015)
- **ABDC** – ABDC 2016 Ranking ("Australian Business Deans Council")
- **WI-List** – Ranking based on WKWI ("Wissenschaftliche Kommission für Wirtschaftsinformatik") WI journal list (2008)
- **IF** – Thomson-Reuters Impact Factor

I fulfilled this requirement by publishing the sole-authored article, “Comprehension of Procedural Visual Business Process Models – A Literature Review,” in the journal *Business & Information Systems Engineering (BISE)* in 2017. In addition, two sole-authored conference papers are submitted as part of this habilitation, presented, respectively, at the European Conference of Information Systems (ECIS) in 2017 and the IEEE Symposium on Visual Languages and Human-Centric Computing (VL-HCC) in 2012.

3.3 Habilitation Requirement 3

The third requirement for the habilitation is that five (or more) published articles have the usual number of two to three authors and that, if four or more authors are listed, the applicant’s contribution should be discussed:

> In den übrigen Aufsätzen sollte die fachinternationale übliche Autorenzahl (ca. zwei bis drei Autoren) nicht überschritten werden. Im Fall von vier oder mehr Autoren ist der eigene Beitrag vom Habilitationswerber eingehend zu begründen. (See habilitation guideline in the Appendix’s section C, p. 63.)

The number of authors in my journal articles varies from one to three, so no discussion of my contribution is necessary. Nevertheless, I like to point out that the order of the articles’ authors is not alphabetical but is based on the authors’ contributions to the research. I was not first author in only one of eight journal articles and only four of fifteen conference papers. In those articles for which I am listed as first author, my intellectual contribution involved performing the experiments, including such tasks “formulating the problem or hypothesis, structuring the experimental design, organizing and conducting the statistical analysis, interpreting the results” (American Psychological Association, 2010, p. 19), writing a major portion of the article and performing the revisions. (Despite my significant contribution as a first author, I use the term “we” when referring to co-authored articles and papers in this habilitation summary.) A notable exception to my being first-author is my collaboration with Dr. Iris Reinhartz-Berger of the University of Haifa, which resulted in one journal article and two conference papers. Dr. Reinhartz-Berger was the first author for those publications, as it was she who asked me to collaborate in the area of software feature models’ comprehensibility. We planned the experimental designs together, I conducted the statistical analysis and wrote about half of the papers and revisions. (My major parts were the theoretical background, the hypothesis-building, the results description and the interpretation.)

3.4 Habilitation: Substitution Option

The habilitation guideline offers a substitution option in case fewer than five journal articles are submitted, allowing three conference publications from very good conferences to substitute for the fourth and fifth journal articles:

> Der vierte und fünfte Artikel kann durch je drei Beiträge zu sehr guten Konferenzen substituiert werden. Sehr gute Konferenzen weisen folgende Eigenschaften auf:
>
> - Die Beiträge werden einem wissenschaftlichen Auswahlprozess aus typischerweise drei oder mehr Peer-Reviews ausgewählt.
> - Die Rückweisungsrate beträgt mehr als 70%
> - Die Konferenzen werden von großen Fachgesellschaften (z.B. ACM, IEEE, IFIP, Usenix, AIS) veranstaltet. (See habilitation guideline in the Appendix's section C, p. 63.)

No substitution was necessary, as I published seven articles in journals on the department's journal list, but I did publish eight papers in conference proceedings for which the organizers reported acceptance rates below or around 30 percent. (See Table 2 for details.)

1. *AIS European Conference of Information Systems (ECIS) 2017* (While the acceptance rate has not yet been published, the conference has recently had acceptance rates of around 30%.)
2. *ACM Software Product Line Conference 2014* (The conference had a 28% acceptance rate, and the paper won the Best Paper Award.)
3. *ACM/IEEE International Conference on Model-Driven Engineering Languages and Systems (MODELS) 2014* (The conference's acceptance rate was 24%.)
4. *European Conference of Information Systems (ECIS) 2013* (32% acceptance rate)
5. *Advanced Information Systems Engineering Workshops 2012.* (30% acceptance rate)
6. *International Conference on Conceptual Modeling (ER) 2011* (16% acceptance rate)
7. *International Conference on Advanced Information Systems Engineering (CAISE) 2011* (15% acceptance rate)
8. *Business Information Systems (BIS) 2010* (<30% acceptance rate)

Table 2. Papers in Peer-Reviewed Conference Proceedings with Acceptance Rates ≤ 30% and Papers at the European Conference of Information Systems (ECIS)[2]

Reference	Full Reference	Acceptance Rate	VHB -JQ3	WI-List
Paper 1 (Figl, 2017b)	Figl, Kathrin (2017). **User Evaluation of Symbols for Core Business Process Modeling Concepts**. 25th European Conference of Information Systems (ECIS). Guimarães, Portugal. (accepted) [Acceptance rate not yet published, the conference recently had acceptance rates around 30%.]	~30%	B	A
Paper 2 (Reinhartz-Berger, Figl and Haugen, 2014)	Reinhartz-Berger, I., Figl, Kathrin (2014). **Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM**. 18th Software Product Line Conference, Florence, Italy: ACM. **(Best Paper Award)**	28%	-	-
Paper 3 (Reinhartz-Berger and Figl, 2014)	Reinhartz-Berger, I., Figl, Kathrin, Haugen, Ø (2014). **Comprehending Feature Models Expressed in CVL**. 17th ACM/IEEE International Conference on Model-Driven Engineering Languages and Systems (MODELS), Valencia, Spain, Springer International Publishing: 501-517.	24%	-	-
Paper 4 (Figl, Koschmider and Kriglstein, 2013)	Figl, Kathrin, Koschmider, A., Kriglstein, S. (2013). **Visualising Process Model Hierarchies**. European Conference of Information Systems (ECIS), Utrecht, The Netherlands.	32%	B	A
Paper 5 (Figl and Weber, 2012)	Figl, Kathrin, Weber, B. (2012). **Individual Creativity in Designing Business Processes.** Advanced Information Systems Engineering Workshops. Lecture Notes in Business Information Processing. Volume 112, 294-306. Berlin: Springer.	30%	C	B
Paper 6 (Figl and Derntl, 2011)	Figl, Kathrin, Derntl, M. (2011). **The Impact of Perceived Cognitive Effectiveness on Perceived Usefulness of Visual Conceptual Modeling Languages.** 30th International Conference on Conceptual Modeling (ER 2011). Lecture Notes in Computer Science, Volume 6998/2011, Brussels, Belgium, 78-91.	16%	B	B
Paper 7 (Figl and Laue, 2011)	Figl, Kathrin, Laue, R. (2011). **Cognitive Complexity in Business Process Modeling**. 23rd International Conference on Advanced Information Systems Engineering (CAISE). Lecture Notes in Computer Science, Volume 6741/2011, 452-466.	15%	C	B
Paper 8 (Figl et al., 2010b)	Figl, Kathrin, Mendling, J., Strembeck, M. & Recker, J. (2010). **On the Cognitive Effectiveness of Routing Symbols in Process Modeling Languages.** Business Information Systems (BIS) 2010. Lecture Notes in Business Information Processing. Volume 47. Berlin: Springer.	<30%	C	B

[2] Explanation of table columns:

- **VHB-JQ3** – Ranking based on German Academic Association for Business Research (VHB) - Jourqual 3 (2015)
- **WI-List** – Ranking based on WKWI ("Wissenschaftliche Kommission für Wirtschaftsinformatik") WI journal list (2008)

3.5 Habilitation Requirement 4

Another requirement for the habilitation is that the applicant has additional publications and presentations at conferences:

> Vom Habilitationswerber werden zusätzlich weitere Publikationen und Vorträge auf einschlägigen Konferenzen, erwartet. (See habilitation guideline in the Appendix's section C, p. 62.)

In addition to the seven journal articles and eight papers in high-quality conferences, I have published several other papers (See Table 3 for details.):

1. *Journal of Visual Languages & Computing (JVLC)*
2. *International Workshop on Cognitive Aspects of Information Systems Engineering 2017*
3. *International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA) 2016*
4. *Software Engineering 2016*
5. *IEEE International Workshop on Compliance, Evolution and Security in Intra- and Cross-Organizational Processes 2016*
6. *Business Process Management Workshops 2015*
7. *International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA) 2015*
8. *International Conference on Software Engineering and Applications 2012*
9. *IEEE Symposium on Visual Languages and Human-Centric Computing 2012*
10. *International Workshop on Enterprise Modeling and Information Systems Architectures 2011*
11. *GI-Workshop EPK: Geschäftsprozessmanagement mit Ereignisgesteuerten Prozessketten 2009*

Table 3: Additional Publications and Presentations at International Conferences

Reference	**Full Reference**	**Additional Information**
Journal Article 8 (Figl et al., 2010a)	Figl, Kathrin, Derntl, M., Rodriguez, M. C., & Botturi, L. (2010). Cognitive Effectiveness of Visual Instructional Design Languages. **Journal of Visual Languages & Computing**, 21(6), 359-373.	IF: 0.63
Extended Abstract 1 (Figl, 2017c)	Figl, Kathrin (2017). **Why are Process Models Hard to Understand? (Keynote)** Lecture Notes in Business Information Processing. 5th International Workshop on Cognitive Aspects of Information Systems Engineering – COGNISE'17 in Conjunction with CAiSE'17. Essen, Germany.	**Invited Keynote** Presentation of Article 1

Reference	Full Reference	Additional Information
Extended Abstract 2 (Figl and Recker, 2016c)	Figl, Kathrin, & Recker, J. (2016). **Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams [Extended Abstract].** International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA), Vienna, Austria.	Presentation of Article 3
Extended Abstract 3 (Figl and Laue, 2016)	Figl, Kathrin, & Laue, R. (2016). **Kognitive Belastung als lokales Komplexitätsmaß in Geschäftsprozessmodellen**. Software Engineering, Gesellschaft für Informatik (GI), Lecture Notes in Informatics (LNI),Vienna, Austria.	Presentation of Article 5
Paper 9 (Dangarska, Figl and Mendling, 2016)	Dangarska, Z., Figl, Kathrin, Mendling, J. (2016). **An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN).** IEEE 2nd International Workshop on Compliance, Evolution and Security in Intra- and Cross-Organizational Processes, Vienna, Austria.	
Paper 10 (Koschmider, Figl and Schoknecht, 2015)	Koschmider, A., Figl, Kathrin, Schoknecht, A. (2015). **A Comprehensive Overview of Visual Design of Process Element Labels**. Business Process Management Workshops. Lecture Notes in Business Information Processing. Innsbruck, Austria.	VHB-JQ3: C
Paper 11 (Figl and Strembeck, 2015)	Figl, Kathrin, Strembeck, M. (2015). **Findings from an Experiment on Flow Direction of Business Process Models**. International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA). Lecture Notes in Informatics (LNI), Innsbruck, Austria.	VHB-JQ3: C, WI-List B
Paper 12 (Figl and Strembeck, 2014)	Figl, Kathrin, Strembeck, M. (2014). **On the Importance of Flow Direction in Business Process Models**. 9th International Conference on Software Engineering and Applications, Vienna, Austria: Scitepress.	Poster Presentation
Paper 13 (Figl, 2012)	Figl, Kathrin (2012). **Symbol Choice and Memory of Visual Models.** IEEE Symposium on Visual Languages and Human-Centric Computing (VL-HCC), Innsbruck, Austria. IEEE Computer Society, 97-100.	Short Paper
Paper 14 (Figl and Weber, 2011)	Figl, Kathrin, Weber, B. (2011). **Creative Personality and Business Process Redesign.** 4th International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA), Hamburg, Germany, Lecture Notes in Informatics 190 GI, 189-194.	Research-in-Progress Paper
Paper 15 (Figl, Mendling and Strembeck, 2009)	Figl, Kathrin, Mendling, J. & Strembeck, M. (2009). **Towards a Usability Assessment of Process Modeling Languages.** GI-Workshop EPK 2009: Geschäftsprozessmanagement mit Ereignisgesteuerten Prozessketten. CEUR-WS: Berlin.	

4 Cognitive Effectiveness in Human Interactions with Conceptual Models

A basic precondition for efficient human interaction with a model is that the model does not overwhelm the user's working memory. Working memory may become a bottleneck in comprehending, analyzing or designing complex models because it limits the amount of information that can be comprehended at any one time (Baddeley, 1992). The cognitive load theory (Sweller, 1988), which provides a general framework for designing the presentation of instructional material to ease learning and comprehension, can also be applied to human interaction with conceptual models.

I have researched a variety of factors related to human interaction with conceptual models. Figure 1 presents a framework that I developed in the context of my habilitation (Figl, 2017a) and that provides a good overview of the variables that I have addressed in my experiments and studies. All of these variables are relevant to cognitive load when people interact with models.

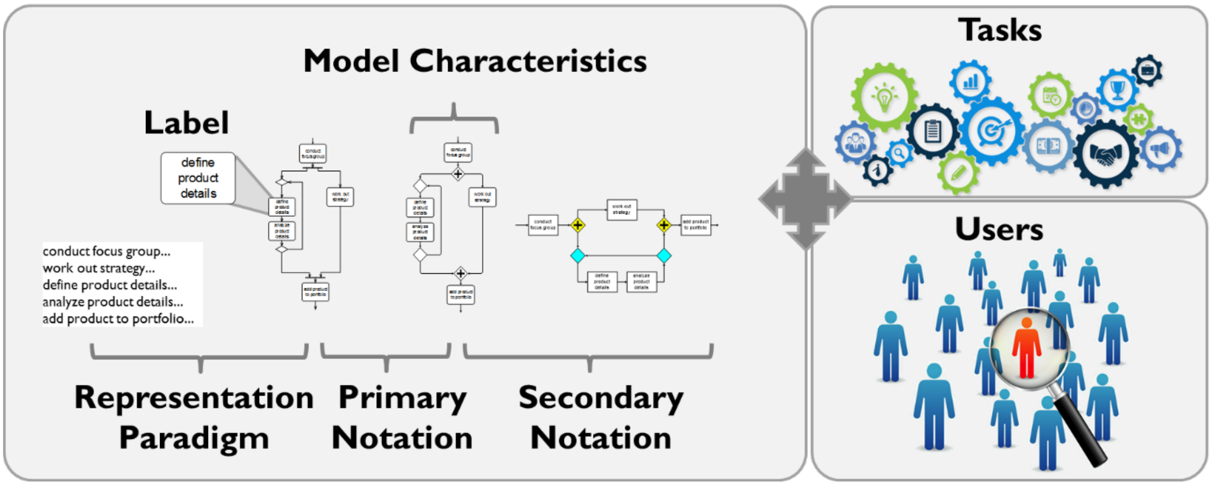

Figure 1. Overview of Variable Types (adapted from Figl (2017a)

The working memory's capacity should be available for "germane" cognitive load—that is, for processing the information and the construction of mental structures that organize elements of information into meaningful patterns (i.e., schema). Intrinsic cognitive load is concerned with the "complexity of information that must be understood" (Sweller, 2010, p. 124). Together, the characteristics of the conceptual model, such as model-based metrics [Figure 1: "**Model Characteristics**"], and the content of the labels [Figure 1: "**Label**"] are relevant to a model's intrinsic cognitive load.

While it is difficult to change a conceptual model's intrinsic cognitive load without changing the content of the domain that it models, changing the visual presentation can have a significant impact on cognitive load without changing the modeled domain. How a conceptual model is visualized relates to the "extraneous" cognitive load (Kirschner, 2002) [Figure 1: "**Representation Paradigm**"]. If the same model is modeled using different notations [Figure 1: "**Primary Notation**"] or using another layout or color highlighting [Figure 1: "**Secondary Notation**"], the resulting models will have comparable intrinsic cognitive load but differ in their extraneous cognitive load, affecting task difficulty (Chandler and Sweller, 1996).

Concerning the task setting [Figure 1: "**Tasks**"], the users' interaction with modeling notations includes the creation (authoring) of models, and the model's ability to be understood (assimilated) (Gemino and Wand, 2004). A global Delphi study by Indulska et al. (2009) identified four main application tasks of models for conceptual models in the business process domain: understanding, communication, execution (to derive system requirements) and improvement (to identify weaknesses in a domain and to develop improvement ideas). The research in this habilitation focuses on the task areas that most involve human cognition: *model creation* (see e.g., Reinhartz-Berger, Figl and Haugen, 2017), *model comprehension* (either directly measured or indirectly relevant to all of the habilitation's articles and papers) and *generating creative improvement ideas* for a domain based on models (see e.g., Figl and Recker, 2016b; Figl and Weber, 2011, 2012). The measurement of a model's comprehension is difficult because the outcome is "tacit understanding created in the model viewers' cognition" (Gemino and Wand, 2004, p. 251). Most of the studies in the habilitation used two objective indicators for model comprehension—comprehension accuracy (typically measured with true/false questions) and time taken, which is in line with other conceptual model-comprehension studies (Gemino and Wand, 2004; Houy, Fettke and Loos, 2012). Regarding the generation of creative improvement ideas, business process improvement can be characterized as a creative problem-solving task (Akin and Akin, 1998) in which the analysts are required to develop original and appropriate solutions for a novel organizational reality in the form of a "to-be" model that is based on an "as-is" model (Kettinger, Teng and Guha, 1997).

Moreover, individuals differ in their processing capacity [Figure 1: "**Users**"]. Cognitive load is higher for novices than it is for experts because novices lack experience and have not yet developed and stored in long-term memory the schemas that would ease processing. Knowledge and experience with the type of model tend to facilitate better and faster interactions with it, regardless of the cognitive load.

Journal Article 1: Figl, Kathrin (2017). Comprehension of Procedural Visual Business Process Models. Business & Information Systems Engineering 59, 41-67.

The framework in Figure 1 is based on (Figl, 2017a), my single-authored article. The aim of the article was to clarify the sources of cognitive effort in comprehending a business process model. Visual process models depict the flow of an organization's logically related tasks, and process modeling is at the core of designing information systems. Low reuse of process models and errors in existing collections of process model show that process models can be difficult for people to create and understand. Process model comprehension is an active research field in which the number of empirical studies on the cognitive aspects of process models is increasing rapidly. Prior contributions in this area had examined a variety of influence factors in isolation, so a comprehensive body of knowledge that provides an overview of the field of process model comprehension was lacking. My article undertook a comprehensive descriptive review of empirical and theoretical work in order to categorize and summarize systematically existing findings on the factors that influence the comprehension of visual process models. Methodologically, the article built on a review of forty empirical studies that measured the objective comprehension of process models, seven studies that measured subjective comprehension and user preferences, and thirty-two theoretical articles that discussed the factors that influence the comprehension of process models. Studies that were selected for the review included an experimental design with at least one experimental condition with a "visual process model" and at least one dependent variable on model comprehension or user preferences.

The review article presented and discussed all of the main effects on model comprehension. As the review article spanned all types of independent variables, insights from the review are presented in the respective sections of the habilitation summary. Table 4 provides an overview of all of the categories of factors that influence process model comprehension and presents examples of the types of variables depicted in Figure 1.

Table 4. Influence Factors for Process Model Comprehension

Main Categories	Exemplary Subcategories
Presentation Medium	e.g., paper versus computer
Notation	representation paradigm (e.g., text versus model, animation and visualization techniques), primary notation (e.g., BPMN, UML AD, YAWL, EPCs), notational characteristics (e.g., semiotic clarity, perceptual discriminability)

Main Categories	Exemplary Subcategories
Secondary Notation	e.g., decomposition, highlighting of control blocks, swim-lanes, layout
Label	label design, naming conventions
Model Characteristics	size measures, modularity and block structuredness, gate-way interplay and control structures
Task	e.g., wording of comprehension tasks
User	domain knowledge, experience and familiarity with pro-cess modeling, modeling knowledge

Almost half of the forty-seven studies reviewed for the paper included notation or user characteristics as influence factors. About 20 percent of the studies took either model-related variables or task-related variables into account, while variables that were related to secondary notation and labels were investigated less frequently.

Overall, the literature review yields cumulative evidence for a variety of variables that are related to comprehending process models and also identified research gaps. As a result, the article provides recommendations for new research questions to be addressed and methods to be used in future experiments. Future work is advised to adopt eye-tracking, which can detect variations in mental effort more precisely than can traditional multiple choice tasks that are used to measure comprehension. Taken together, the review updates researchers on current empirical research, contrasts it with existing modeling guidelines and contributes to the vibrant stream of research on process model comprehension.

5 Modeling Notation

Because of the positive effects of conceptual modeling in facilitating a common understanding between users and system engineers, a large number of modeling approaches that target various levels and viewpoints within information systems—and that also address various domains—have been proposed. However, there is a discrepancy between the attention paid to creating and developing modeling notations in research and their actual use by practitioners in real-world applications.

A variety of underlying cognitive theories have been adopted with regard to the context of visual modeling, often in an attempt to define the desirable characteristics of a notation to fully benefit from the visual representation. Examples include cognitive load theory (Sweller, 1988), cognitive fit theory (Vessey, 1991), the cognitive dimensions framework for notational systems (Green and Petre, 1996) and the theory of multimedia learning (Mayer, 2001). Moody (2009) proposed nine principles for the cognitively effective design of visual notations: semiotic clarity, graphic economy, perceptual discriminability, visual expressiveness, dual coding, semantic transparency, cognitive fit, complexity management and cognitive integration. Many studies in this habilitation thesis refer to one or more of these principles. Two experiments performed provide the first empirical proof that criteria like semiotic clarity, perceptual discriminability and semantic transparency actually affect comprehension (Figl, Mendling and Strembeck, 2013; Figl, Recker and Mendling, 2013).

Semiotic clarity refers to the importance of a one-to-one correspondence between selected concepts and their visual representation by a symbol. Anomalies like symbol redundancy (more than one symbol representing the same concept), overload (one symbol representing more than one concept), and symbol excess and deficit (graphical symbols that do not correspond to a semantic construct, or vice versa) should be avoided since they lead to ambiguity and unnecessary cognitive load for the user (Moody, 2009). A reasonable balance between a notation's expressiveness and the number of symbols is demanded by the principle of **graphic economy**. **Perceptual discriminability** refers to the "ease and accuracy with which graphical symbols can be differentiated from each other" (Moody, 2009, p. 762). Visual notations that fully exploit the range of visual variables (e.g., spatial dimensions, shape, size, color, brightness, orientation and texture) for their symbols increase **visual expressiveness.** A wise combination of text and graphical representation is referred to as **dual coding**, and **semantic transparency** describes whether symbols and their corresponding real-world concepts are easily associated (Moody, 2009). **Cognitive fit** refers to the fit between the problem representation and the strategies required to perform a specific task (Vessey, 1991). Therefore, because a visual language's cognitive effectiveness might differ for experts and beginners, a notation could provide different visual dialects for each user group or task to improve its cognitive fit for each group (Moody, 2009). A notation should provide mechanisms to **manage complexity** in order to impose a cognitive load on users that is as light as possible. Two main mechanisms can be applied to manage complexity: hierarchical structuring and modularization. Hierarchical structuring provides different levels of detail (abstraction vs. decomposition), which makes complex concepts more easily understandable (Moody, 2009). Modularization works by dividing complex domains into smaller parts, as a large problem becomes more easily manageable if it is broken down into separate parts. Modularization, or providing multiple perspectives, leads to multiple diagrams that belong together and represent a domain. The principle of **cognitive integration** (Moody, 2009) helps people to understand the relationships among models.

Aesthetics are relevant to symbol characteristics because, “up to some point, the design and appreciation of a symbol remains subject to subjective evaluation” (Figl, Recker and Mendling, 2013, p. 1106). Research in the area of icons has reported that appeal ratings also reflect the users’ unconscious awareness of the ease with which the visual stimuli are cognitively processed (McDougall et al., 2016).

The broad spectrum of available modeling notations makes users’ beliefs and choices an important issue. Since the objective of using a conceptual model or a modeling notation can be influenced by a variety of external factors, perceived usefulness is generally a robust success measure (Maes and Poels, 2007). The perception of a modeling notation’s (cognitive) effectiveness is likely to influence whether users perceive it to be useful enough to use.

Paper 6: Figl, Kathrin, Derntl, M. (2011). The Impact of Perceived Cognitive Effectiveness on Perceived Usefulness of Visual Conceptual Modeling Languages. 30th International Conference on Conceptual Modeling (ER 2011). Lecture Notes in Computer Science, Volume 6998/2011, Brussels, Belgium, 78-91.

The paper “The Impact of Perceived Cognitive Effectiveness on Perceived Usefulness of Visual Conceptual Modeling Languages” (Figl and Derntl, 2011) examined the relationship between users’ perception of a conceptual modeling notation’s quality and usefulness from a cognitive point of view. Using validated measures from Maes and Poels (2007) to measure perceived usefulness, the paper builds on Moody’s (2009) framework for cognitively effective design of visual notations. An empirical study with 198 user ratings of diagrams drawn using different modeling notations in the instructional design domain provides evidence that users’ perceptions of criteria like perceptual discriminability, graphic economy, a balanced combination of text and symbols, and semiotic clarity influence their perceptions of the usefulness of visual conceptual modeling notations.

5.1 Primary Notation

In the context of this habilitation, I follow Moody (2009, p. 756), who defines visual notation as “a set of graphical symbols (visual vocabulary) [and] a set of compositional rules (visual grammar).” The choice of modeling notation is particularly relevant because “the world (reality) is never given to us in and of itself, but only through interpretation in some language” (Hirschheim, Klein and Lyytinen, 1995, p. 148).

5.1.1 Process Modeling Notations

Visual process models support people in analyzing and improving complex organizational processes. Since its emergence in the 1970s, process modeling has grown to become one of the most important areas of conceptual modeling (Melão and Pidd, 2000), and a great wealth and variety of existing process modeling notations have been proposed as Event-driven Process Chains (EPCs), UML Activity Diagrams (UML ADs), YAWL, and BPMN. Process modeling notations "tend to emphasize diverse aspects of processes, such as task sequence, resource allocation, communications, and organizational responsibilities" (Soffer and Wand, 2007, p. 176). Most process modeling notations share a basic set of concepts but use divergent symbols to represent them. Although these notations are visual notations and the design of a symbol influences, for example, whether the symbol is easy to spot in a model and is correctly associated with the concept it represents, little attention has been devoted to the choice of symbols.

Paper 15: Figl, Kathrin, Mendling, J. & Strembeck, M. (2009). Towards a Usability Assessment of Process Modeling Languages. GI-Workshop EPK 2009: Geschäftsprozessmanagement mit Ereignisgesteuerten Prozessketten. CEUR-WS: Berlin.

In a first theoretical paper, "Towards a Usability Assessment of Process Modeling Languages" (Figl, Mendling and Strembeck, 2009), we discussed differences in process modeling notations based on their cognitive effectiveness when one tries to learn them and when one uses them to create and understand models. In this paper, we analyzed the symbols sets of UML AD, YAWL, BPMN, and EPCs according to the principles of semiotic clarity, perceptual discriminability, semantic transparency, visual expressiveness and graphic economy. The preliminary evaluation of these modeling notations' cognitive effectiveness provides a basis for further empirical studies in the habilitation thesis.

Paper 8: Figl, Kathrin, Mendling, J., Strembeck, M. & Recker, J. (2010). On the Cognitive Effectiveness of Routing Symbols in Process Modeling Languages. Business Information Systems (BIS) 2010. Lecture Notes in Business Information Processing Volume 47. Berlin: Springer.

A second theoretical paper, "On the Cognitive Effectiveness of Routing Symbols in Process Modeling Languages" (Figl et al., 2010b), focused on process modeling notations' routing symbols and analyzed their differences using considerations related to cognitive effectiveness. Routing symbols like AND and XOR express the convergence or divergence semantic in a process model. We applied as criteria semiotic clarity, perceptual discriminability, semantic transparency, visual expressiveness and graphic economy in the analysis of the routing elements of UML AD, YAWL, BPMN, and EPCs. We drew conclusions that are relevant to the usefulness of these notations in business process modeling projects.

Paper 1: Figl, Kathrin (2017). User Evaluation of Symbols for Core Business Process Modeling Concepts. 25th European Conference of Information Systems (ECIS). Guimarães, Portugal.

The major goal of the study presented in the paper "User Evaluation of Symbols for Core Business Process Modeling Concepts" (Figl, 2017b) was to assess users' perceptions of the relative strengths and weaknesses of the symbols used in EPC, UML, YAWL, and BPMN for basic process modeling concepts. In an empirical study with 188 participants, normative ratings of process model symbols (for the basic concepts of start, end, task, AND and XOR) were gathered on the dimensions of perceptual pop-out, semantic transparency, perceptual discriminability and aesthetics. Overall, the results are consistent with predictions that were based on theoretical analyses of the symbols' designs (Figl, Mendling and Strembeck, 2009; Figl et al., 2010b). (Results concerning task symbols and labels are presented in section 7.2.)

Users rated YAWL's start and end symbols the best among the notations, but they rated YAWL's AND and XOR symbols worse than the routing symbols other notations use. The result likely occurred because YAWL's start and end symbols have higher semantic transparency than other symbols do, and the AND and XOR symbols were rated lower because they were more difficult to discriminate.

Prior familiarity with process modeling notations led to more clear-cut evaluations of routing symbols (AND, XOR) and a reduced tendency to prefer middle rating options, but it did not affect the other symbols' evaluations. Standardization organizations and academic developers of notations can use insights from the study to enhance the usability of process modeling notations.

Paper 13: Figl, Kathrin (2012). Symbol Choice and Memory of Visual Models. IEEE Symposium on Visual Languages and Human-Centric Computing (VL-HCC), Innsbruck, Austria. IEEE Computer Society, 97-100.

A small-scale experiment, described in the paper "Symbol Choice and Memory of Visual Models" (Figl, 2012), investigated how symbol choice in process modeling notations (UML, BPMN, YAWL) affects the ease with which people can memorize and recall process models. Quantitative analysis of data collected from thirty-seven business school students revealed that symbol choice significantly influenced the ability to remember the diagrams' visual aspects as layout. The experimental groups differed in their performance in all visual recall tasks related to routing symbols. For instance, participants misjudged the original number of ANDs and XORs in the experimental condition YAWL more often than they did in the experimental condition BPMN and recognized fewer changes in the control flow and layout in the experimental condition YAWL than in the BPMN and UML AD conditions. On the other hand, participants scored equally well in estimating the number of activities, and symbol choice had no significant effect on the participants' ability to recognize the diagrams' semantic content. Overall, the findings indicate that symbol choice is relevant to the design of visual notations. The symbols that were identified as inferior in cognitive effectiveness reduced the participants' performance in visual recall.

5.1.2 Decision Model and Notation (DMN)

Decision models are usually created to complement business process models and to separate additional information regarding decision-making from process models. Decision Model and Notation (DMN) was released in 2015 as an OMG (Object Management Group) standard.

Paper 9: Dangarska, Z., Figl, Kathrin, Mendling, J. (2016). An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN). IEEE 2nd International Workshop on Compliance, Evolution and Security in Intra- and Cross-Organizational Processes, Vienna, Austria.

The paper "An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN)" (Dangarska, Figl and Mendling, 2016) analyzed DMN's visual notation from a cognitive point of view and presented findings on DMN's conformity with criteria for effective visual design. While the principles of semiotic clarity, visual expressiveness, complexity management and cognitive integration appeared to be satisfied for the most part, visual expressiveness and perceptual discriminability were perceived to be partly violated. The goal of this first qualitative analysis was to lay the foundation for follow-up empirical investigations.

5.1.3 Software Feature Modeling Notations

Another area of research for my habilitation thesis focused on modeling of software features. Feature modeling is a common way to present the variability of systems. As the complexity and variety of systems and software products increase, managing them effectively becomes more difficult. The engineering of software product lines is related to systematic reuse, as all products in a product line have common features, and commonality and variability are systematically planned. A feature/variability model is a tree or graph that describes the features of a software product line that are visible to the end user and the relationships and dependencies between the features (Czarnecki and Eisenecker, 2000). Such variability models can augment human cognitive capacity because they make the complex structures of the domain visually available as externalized semantic memory structures. Despite considerable attention in research on variability modeling, no empirical study had examined the comprehensibility of variability modeling notations.

Paper 2: Reinhartz-Berger, I., Figl, Kathrin (2014). Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM. 18th Software Product Line Conference, Florence, Italy: ACM. **(Best Paper Award)**

In the paper "Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM" (Reinhartz-Berger, Figl and Haugen, 2014) we examined potential comprehension problems in two common orthogonal variability modeling notations: Common Variability Language (CVL), which was recommended for adoption as a standard by the Architectural Board of the Object Management Group, and Orthogonal Variability Model (OVM). This paper won the best research paper award at the ACM Software Product Line Conference.

We conducted an exploratory experiment with forty-five participants. CVL and OVM were similar in terms of comprehension score and time spent to complete tasks, and we found no significant differences in comprehension between the two modeling notations we investigated, CVL and OVM. The most likely explanation for this finding is that the two notations use similar symbols (rectangles and triangles) and syntactic rules. Both notations could be recommended to a similar extent, but users rated CVL as more comprehensible and easier to learn than OVM, perhaps because of some minor shortcomings of OVM's visual notation. The findings from our study might inform ongoing revisions of CVL and OVM.

5.1.4 Instructional Design Notations

The introduction of learning technologies into education is making the design of courses and instructional materials increasingly complex. Instructional designers—architects of learning environments—use domain-specific instructional design notations to model the various aspects of courses that involve the use of new media.

Journal Article 8: Figl, Kathrin, Derntl, M., Rodriguez, M. C., & Botturi, L. (2010). Cognitive Effectiveness of Visual Instructional Design Languages. Journal of Visual Languages & Computing, 21(6), 359-373.

In the article "Cognitive Effectiveness of Visual Instructional Design Languages" (Figl and Derntl, 2011) we presented the results of domain experts' (n = 20) evaluations of cognitive aspects of three visual instructional design notations: E²ML, PoEML, and coUML. The findings enable language constructors to improve the usability of future visual instructional design notations, and the article gave directions how future research on how instructional design notations can enhance their use by educators and designers by synthesizing existing efforts into a unified modeling approach for visual instructional design notations.

5.2 Notational Characteristics

When comparing notations as a whole without isolating notational characteristics, models differ based on many variables (e.g., numbers of symbols), so it is difficult to suggest how to improve a notation and to determine which cognitive effectiveness criteria are most relevant to their improvement. Therefore, in two experiments (Figl, Mendling and Strembeck, 2013; Figl, Recker and Mendling, 2013) I isolated notational characteristics like semantic transparency and perceptional discriminability in order to generalize the results beyond specific notations. These experiments did not always adhere to the syntactic restrictions of modeling notations in their experimental material but focused instead on varying certain notational characteristics in order to achieve internal validity and to determine what affects a model's comprehension. Overall, these two studies provide empirical evidence of the importance of symbol design for (process) model comprehension and put the cognitive effectiveness criteria from Moody (2009) to an empirical test. In both studies perceptual pop-out and perceptual discriminability show their relevance to comprehension accuracy and perceived cognitive load.

Journal Article 6: Figl, Kathrin, Mendling, J., & Strembeck, M. (2013). The Influence of Notational Deficiencies on Process Model Comprehension. Journal of the Association for Information Systems, 14(6), 312-338.

In the article "The Influence of Notational Deficiencies on Process Model Comprehension" (Figl, Mendling and Strembeck, 2013) we investigated whether the basic symbol sets in visual process modeling notations influence the comprehension and cognitive load of process models. For this purpose, we investigated four symbol sets in an experiment with 136 participants who carried out model-comprehension tasks.

We compared the reference values of two notations that have no global deficiencies (UML AD, BPMN) with a notation that has deficiencies in perceptual discriminability (YAWL) and a notation that has deficiencies in semiotic clarity (EPC). Our results indicate that notational deficiencies concerning perceptual discriminability and semiotic clarity have measurable effects on comprehension, cognitive load, and the time needed to understand the models. Results show that the perceptual discriminability deficiencies of symbols in YAWL and the semiotic clarity deficiencies of symbols in EPC lowered comprehension accuracy below those of UML AD and BPMN.

Our research informs work on the evaluation of modeling notations in two primary ways. First, the results of this article suggest that future research into the comprehension of (process) models should consider symbol sets and syntactical factors in isolation when investigating the relative superiority of different (process) modeling notations. Second, our results emphasize the importance of visual discriminability. In practice, the development of (new) domain-specific modeling notations can benefit from our results. Here, the recommendations of the "physics of notations" (Moody, 2009) can be applied with a much higher level of design freedom to design suitable symbol sets, as opposed to standardized notations, which must be consistent with prior versions of the standard.

Journal Article 7: Figl, Kathrin, Recker, J., & Mendling, J. (2013). A Study on the Effects of Routing Symbol Design on Process Model Comprehension. Decision Support Systems 54(2), 1104-1118.

In the article "A Study on the Effects of Routing Symbol Design on Process Model Comprehension" (Figl, Recker and Mendling, 2013) we took a detailed look at routing symbols in process models. We conducted an experiment with 154 students to ascertain which visual design principles used in the design of routing symbols influence the comprehension of process models. No existing scales or questionnaires were available with which to assess the users' evaluations of cognitive effectiveness criteria, so I developed appropriate scales for semantic transparency, perceptual discriminability, pop-out, and aesthetics. This work was the first effort to operationalize and measure principles of the effective design of visual notation. Future studies can use the measurement instruments provided, with three to four items on each dimension.

The findings of the study suggest that design principles related to perceptual discriminability and pop-out improve comprehension accuracy and perceived comprehension of control flow and lowered the perceived cognitive load. In contrast, characteristics like semantic transparency and aesthetics, which relate to later stages of perceptional processing, lowered the perceived cognitive load but did not directly affect comprehension accuracy. Overall, our results inform important principles about the design of process modeling notations.

5.3 Representation Paradigm

Next, I summarize my studies that have challenged the assumption that using a modeling notation instead of alternative representation paradigms is always the best choice. "Alternative" representations may be textual descriptions, domain semantic-oriented pictorial elements like icons and images that are assigned to modeling elements, animation, narration and visualization techniques (Figl, 2017a).

In the area of process models, prior empirical research has found a moderate level of evidence that experienced users perform better in comprehension tasks with BPMN models than they do with textual process descriptions, while there was no difference among inexperienced users (Ottensooser et al., 2012; Rodrigues et al., 2015). In my habilitation I investigated whether the superiority of diagrammatic representations can be generalized from comprehension tasks to other task settings.

5.3.1 The Representation Paradigm and User Preferences for Different Tasks

Journal Article 3: Figl, Kathrin, & Recker, J. (2016). Exploring Cognitive Style and Task-Specific Preferences for Process Representations. Requirements Engineering, 21(1), 63-85.

In the article “Exploring Cognitive Style and Task-Specific Preferences for Process Representations” (Figl and Recker, 2016a) we investigated which representations users prefer when they work on application tasks related to process modeling. Processes can be described using unstructured, semi-formal or diagrammatic representation forms that are used in a variety of task settings, ranging from understanding processes to executing and improving processes, with the implicit assumption that the chosen form of representation is appropriate in all task settings. We explored the validity of this assumption by examining empirically the preference for various process representation forms (text, structured text, diagram (BPMN); with/without icons) depending on the task setting (and the user’s cognitive style; see section 10.3). We compared the preference for particular representation formats (e.g., text over diagram) for each of four task settings (understanding the process, communicating the process to someone who is unfamiliar with it, supporting developers of an IT-based system in executing the process, and identifying opportunities to improve how the process is executed). Participants (n=120) used sliders that measured preference for one representation format over another on an unnumbered graphical scale from representation format A to representation format B. Such graphical rating scales offer reliable scores and the “psychometric advantage of communicating to respondents that they are responding on an interval continuum” (Cook et al., 2001, p. 705). Using statistical analysis of the resulting empirical data, we were the first to show task-specific differences in preferences for the various representation formats used for business processes. Diagrams were most preferred for all four tasks, and structured text was consistently preferred over text. These results are in line with related studies and may reflect diagrams' ability to ease users in eliminating irrelevant information and reducing cognitive effort. Still, the data suggest that preferences for particular forms of representation vary, at least in part, based on the type of task. For instance, the preference for diagrams over text changes significantly depending on the task setting: diagrams are preferred over text in understanding processes, but the degree to which diagrams are preferred is less than it is for the three other task settings. Our study also provided some evidence that icons (attached to activity symbols that express the semantic meaning of the process activities) can be preferable additions in understanding and communicating, but not for all model-based tasks. This finding supports the argument that iconic representations are helpful in understanding processes (Mendling, Recker and Reijers, 2010).

Regarding implications for practice, our findings can inform revisions of process modeling tools by supporting the use of certain forms of representations and views on a business process for certain tasks. Modeling tools could enable users to switch such features as icons on/off and to auto-generate other forms of representation.

5.3.2 The Representation Paradigm and Its Effect on Creative Redesign of Business Processes

Journal Article 4: Figl, Kathrin, & Recker, J. (2016). Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams. Information & Management, 53(6), 767–786.

Supporting business and systems analysts with process models in idea-generation tasks has been a longstanding topic of interest to researchers. In the article "Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams" (Figl and Recker, 2016b) we examined how process models support process re-design tasks in which analysts generate ideas about novel ways to execute processes. Improving technical or organizational processes typically involves developing "as-is" process models that capture the current organizational reality in order to stimulate ideas about how the current processes can be improved. However, the question concerning whether process models actually assist analysts in finding innovative new solutions for "to-be" processes or whether they limit them to current ways of thinking remains. For example, Rosemann (2006) argued that process modeling focuses on the shortcomings of an existing solution, with the consequence that model-based process innovation concentrates on overcoming existing problems rather than achieving inspirational new goals.

Through an experiment with 108 participants, we compared how two types of models of processes, textual and diagrammatic, assist novice analysts in developing innovative solutions to process redesign tasks. We asked the participants to analyze and redesign a business process for a pizza-delivery service process in the course of three different improvement tasks. We measured the solutions' creativity in terms of fluency (number of ideas), appropriateness and originality (commonly used measures in the creativity literature) and in terms of their impact. In addition, we used a measure we developed for the types of solutions in terms of the locus of change, that is, whether the solutions affect the control flow, information systems, or the organizational, technological, or data components of a business process.

The results from our study indicated that diagrams are superior to textual process descriptions in ensuring the appropriateness of process-redesign ideas and that diagrams tend to produce ideas that are more original and have greater impact, while the number of ideas does not vary significantly. Process diagrams also change the focus of the redesign ideas such that ideas that are related to information systems improvements increase and ideas that are related to enhancing data flow decrease.

While these results demonstrate that diagrammatic models do not make analysts more creative per se or lead to a higher number of ideas, the redesign solutions tend to be more appropriate and beneficial in terms of type of solution. Therefore, our findings did not support the argument that "as-is" process models evoke fixation and hinder the generation of creative, appropriate ideas. Taken together, the findings confirm a commonly held notion that diagrammatic process models are a useful aid to process analysts in designing future processes. One practical interpretation of our findings is that managers can, at least to some extent, guide the development of future processes by selecting a process-representation format that is more or less conducive to producing changes to a business process's control flow, data, resource, or technology components.

6 Secondary Notation

While *primary* notation defines symbols and the rules for combining them, *secondary* notation relates to "things which are not formally part of a notation which are nevertheless used to interpret it … e.g., reading a … diagram left-to-right and top-to-bottom, use of locality (i.e., placing logically related items near each other" (Petre, 2006, p. 293). Moody (2009, p. 760) similarly defined secondary notation as "the use of visual variables not formally specified in the notation to reinforce or clarify meaning." Primary and secondary notations have overlap since some notations define rules on certain aspects of notation that other notations do not. Studies in the area of secondary notation have investigated such variables as decomposition, highlighting of model elements (e.g., using color to highlight elements that belong together), the use of swimlanes in a process models (e.g., to group tasks according to their actors) and the layout of models (Figl, 2017a). My review on process model comprehension showed that additional visual information in a model, such as color or swimlanes, may not always support comprehension and may even lower perceived ease of understanding if the information is not central to the task at hand (Figl, 2017a).

In the context of the habilitation, my aim was to address three research gaps in the area of secondary notation: the overall direction (flow) of process models, the visualization of business process model hierarchies, and modeling styles for modeling software features.

6.1 Direction (Flow) of Process Models

Only a few empirical studies have addressed the layout of process models. Some conceptual work has been done: Bernstein and Soffer (2015) identified process models' key layout features (e.g., symmetry, angles, shape and size, alignment of elements) based on users' perceptions of models' readability and have defined metrics to characterize layout. Schrepfer et al. (2009) proposed how model layout might relate to the model's comprehensibility. Effinger et al. (2011) performed a user evaluation of the criteria for process models' layout (e.g., bending and crossing of edges, arrangement, overlapping and size of elements, coloring), but did not measure the effect of these criteria on the comprehension of process models.

In my habilitation, I addressed the open issue of a model's direction (flow). A core aspect of diagrammatic process modeling is the visualization of the logical and temporal order in which the process's tasks are performed. The convention in today's modeling practice is to model business processes from left to right or from top to bottom. Even though the choice of flow direction changes a process model's visual appearance significantly, this convention is seldom addressed in standard documents and modeling guidelines. In addition, most recommendations related to the flow direction are not based on either scientific claims or empirical evidence regarding their readability.

Paper 12: Figl, Kathrin, Strembeck, M. (2014). On the Importance of Flow Direction in Business Process Models. 9th International Conference on Software Engineering and Applications, Vienna, Austria: Scitepress.

In a first theoretical paper, "On the Importance of Flow Direction in Business Process Models" (Figl and Strembeck, 2014), we discussed the importance of the direction (flow) of process models from a scientific viewpoint. In particular, we gave a comprehensive overview of theoretical perspectives that offer explanations for why a left-to-right flow direction for process models (in countries whose languages read left to right) should be superior to other directions in terms of comprehensibility. One of the arguments is that understanding a process model is easier if its flow direction matches users' expectations (Harsel and Wales, 1987; Krohn, 1983; Winn, 1982) that have been formed by the direction of written language and typical conventions used in visual representations (Tversky, Kugelmass and Winter, 1991; Winn, 1983).

Paper 11: Figl, Kathrin, Strembeck, M. (2015). Findings from an Experiment on Flow Direction of Business Process Models. International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA). Lecture Notes in Informatics (LNI), Innsbruck, Austria.

In the paper "Findings from an Experiment on Flow Direction of Business Process Models" (Figl and Strembeck, 2015) we put the propositions in (Figl and Strembeck, 2014) to an empirical test in order to determine whether some flow directions are cognitively superior to others. The paper presented the results of a controlled pilot experiment (with forty-four participants) that compared the effects of four flow directions (left to right, right to left, top to bottom, bottom to top) on a process model's comprehensibility. Flow direction had no significant main effect on comprehension accuracy, the model's perceived ease of use, or the time taken. Although a variety of theoretical arguments support the use of a left-to-right flow direction as the convention for process models, the preliminary empirical results of the pilot experiment were less clear-cut, as they showed that model readers also adapt well to uncommon reading directions (e.g., right to left). This contradictory result is in line with other research that has found that people adapt quickly to uncommon reading directions in diagrams (Winn, 1983).

6.2 Visualization of (Business Process) Model Hierarchies

In practice, business process models can be complex, and ensuring that large collections of process models are understandable is a challenge for the information systems discipline. Representation of large, complex processes in a single, monolithic model can easily lead to "map shock" in anyone who views it (Moody, 2006a), reducing the motivation to work with it (Blankenship and Dansereau, 2000, p. 295). Managing such complexity can be realized through the concept of hierarchical structuring, also called decomposition (Moody, 2006b), that is, breaking the system into smaller, more easily comprehensible parts. However, decomposition yields another problem, as users have to assimilate relatively independent pieces of information from multiple models simultaneously and integrate them in their minds (Kim, Hahn and Hahn, 2000; Moody, 2006b), increasing cognitive load because of a split-attention effect (Sweller and Chandler, 1994), especially if users are not well supported in navigating among levels of a process's hierarchy. A systematic study on the benefit of process model decomposition should take different visualizations of a process model's hierarchy into account. Because users usually use modeling tools when creating and editing process models, how models and submodels are visually presented and how the user is supported in orientating and navigating through the model structures is relevant to their ability to understand model hierarchies. Methods to support the cognitive integration of submodels include providing summary (overview) models and showing each submodel in the context of the whole system (Kim, Hahn and Hahn, 2000). Interactive visualization techniques may help to represent large process models on limited screen space, prevent the user from losing the overview when they view submodels, and help the user to integrate information from different submodels into a mental whole (North, 2005).

Paper 4: Figl, Kathrin, Koschmider, A., Kriglstein, S. (2013). Visualising Process Model Hierarchies. European Conference of Information Systems (ECIS), Utrecht, The Netherlands.

In the paper "Visualising Process Model Hierarchies" (Figl, Koschmider and Kriglstein, 2013) we sought to gain insights on how to visualize process model hierarchies. While the information systems community has devoted considerable attention to decomposition, as a principle, to manage the complexity of conceptual models, little research has addressed two factors that are relevant to how the model hierarchy is visually represented (visualization) and how users can interact with the hierarchical structure (interface). More specifically, we explored how visualization techniques (e.g., node-link diagrams, treemaps, and nested graphs and interface strategies as overview+detail and focus+context) can be used in visualizing the hierarchical structures of process models.

Using an expert evaluation approach with fifteen experts, we sought to determine whether some visualization strategies fit model hierarchies better than others. We asked participants to use pair-wise comparisons to judge their preferences for using certain visualization and interface strategies with an example of a process model hierarchy visualization. The results of this study indicated that, while experts were indifferent between the treemap and nested graph visualizations, they clearly preferred the node-link visualization over nested graphs and tended to prefer it over treemaps. The experts also tended to prefer the overview+detail strategy over the focus+context strategy to navigate in the hierarchy.

These insights can be used to develop user-centered modeling-tool support. A broader goal of this study was to stimulate discussion about the relevance of visualization techniques to understanding model decomposition.

6.3 Modeling Style for Software Feature Models

A common way to represent software product lines is variability modeling. Yet, there are several ways to extract and organize the characteristics of variability. The resulting models may differ in the characteristics (choices) they contain or in the ways in which these choices are organized.

Journal Article 2: Reinhartz-Berger, I., Figl, Kathrin, & Haugen, Ø. (2017). Investigating Styles in Variability Modeling: Hierarchical vs. Constrained Styles. Information and Software Technology, 87, 81-102.

The goal of the article "Investigating Styles in Variability Modeling: Hierarchical vs. Constrained Styles" (Reinhartz-Berger, Figl and Haugen, 2017) was to determine the comprehensibility of two common ways to organize variability into models, hierarchical and constrained, where the dependencies between choices are specified through the model's hierarchy or as cross-cutting constraints, respectively. We conducted a controlled experiment with ninety participants, all of whom were students with prior training in modeling. Each participant was provided with two variability models specified in CVL and was asked to answer comprehension questions that required to interpret the models. After answering the questions, the participants were asked to use a dedicated CVL tool to create a model based on a textual description without guidance as to the modeling style. We measured the quality of the resulting models in terms of correctness and the participants' reports on the task's difficulty. The number of models created using the natural language description was large, so we let experts encode them independently (e.g., the specification of each requirement, the modeling styles used) and discuss the differences in their coding until they reached full agreement.

Our results indicated that expressing constraints through a repetition-free hierarchy is not always the most comprehensible option that modelers currently believe it is and that modeling guidelines advise (Czarnecki and Wasowski, 2007). Models with high dependency were best understood with hierarchical models, while only models with low dependency had the best fit with the constrained style (the constrained style promotes a repetition-free visual classification tree, while cross-dependencies are specified by textual constraints to restrict the possible set of configurations). These combinations of modeling style and choice interdependency led to a lower number of occurrences of the (non-abstract) choices in the models and, thus, a lower element-interactivity effect and were easier to comprehend. In summary, our study provided further evidence for the utility of cognitive load theory in explaining cognitive difficulties in variability modeling. Even for a single comprehension task, a variety of representations may be beneficial, depending on the inherent structure of the information to be represented. These results can be used to generate teaching materials and modeling guidelines.

With respect to model creation, we found that the use of a constrained modeling style results in variability models that are more likely to be correct. It seemed to be easier for users to first create a redundancy-free hierarchical model of the choices and then to add missing constraints as textual additions.

Prior exposure to modeling style and the degree of dependency among elements in the model determined what modeling style a participant chose when creating the model from natural language descriptions. Visual example models may have a possible constraining effect and lead to inappropriate models if modelers adhere to them too closely. Thus, this study extended research on fixation effects in design tasks to include the area of conceptual modeling. However, our experience was that participants did not blindly adhere to these styles but adapted to the specific circumstances of the choice interdependency. Switching to the constrained modeling style happened more often than not, which seemed to be a wise decision, as models that were modeled in a constrained style were more likely to be correct.

7 Label Characteristics

Label characteristics carry the meaning of the process—that is, the semantic "information." Moody (2009, p. 764) observed that labels "play a critical role at the sentence (diagram) level, in distinguishing between symbol instances (tokens) and defining their correspondence to the real world domain."

Semantic issues related to labeling process models' elements have received more attention than their visual design has (e.g., recommendations on labeling styles or on revising the vocabulary of process models' element labels (e.g., Leopold et al., 2013; Leopold, Smirnov and Mendling, 2012; Mendling, Reijers and Recker, 2010). For instance, current modeling guidelines advocate using a verb-object style (Mendling, Reijers and Recker, 2010), where the object is a noun (or noun compound) and the action is a verb in the infinitive.

7.1 Abstract versus Concrete Labels

Paper 11: Figl, Kathrin, Strembeck, M. (2015). Findings from an Experiment on Flow Direction of Business Process Models. International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA). Lecture Notes in Informatics (LNI), Innsbruck, Austria.

We investigated the semantic aspects of labels in relation to abstract versus concrete labels in one study of my habilitation, although this was not the main variable of interest in this study, but a control variable. The paper "Findings from an Experiment on Flow Direction of Business Process Models" (Figl and Strembeck, 2015) described the study and its results. The experimental design used label semantics as a between-group factor (with two levels: abstract—capital letters; concrete—text label in verb-object style) in addition to the main variable of interest (flow direction; as presented in section 6.1). We found no significant effect of label semantics on comprehension accuracy and perceived ease of use of the model, but it did have a significant effect on the variable of comprehension efficiency. On average, participants took more than a minute longer to answer eight questions about a model with concrete labels (5:36) than with abstract labels (4:02). This result was in line with prior research that found that text labels add cognitive load and increase reading time and the effort required to assemble information, compared to a label that consisted of only a single letter (Mendling, Strembeck and Recker, 2012).

7.2 Visual Design of Labels

In my habilitation thesis, I also investigated the visual design of process element labels. Disciplines in which an efficient presentation of text labels is crucial (e.g., cartography) have continuously improved their visualization design techniques since they serve as effective cognitive aids in problem-solving. Despite the relevance of labels to information exploration, little research has been done on the visual design of business process models' element labels.

Paper 10: Koschmider, A., Figl, Kathrin, Schoknecht, A. (2015). A Comprehensive Overview of Visual Design of Process Element Labels. Business Process Management Workshops. Lecture Notes in Business Information Processing. Innsbruck, Austria.

The paper "A Comprehensive Overview of Visual Design of Process Element Labels" (Koschmider, Figl and Schoknecht, 2015) filled this gap by providing an overview of and guidelines for the visual design of process models' element labels.

We analyzed literature from related disciplines (word recognition in natural language text, source code comprehension) and scanned it for recommendations on how to display process models' element labels visually. The visual design options were discussed in terms of the "graphic design space" (Moody, 2009), which is based on Bertin's (1983) visual variables of shape/form, size, direction/orientation, color, and position. For instance, using lowercase letters for labels was suggested because text in lowercase can be read faster (Sanocki and Dyson, 2012), and Verdana and Arial are considered to be the most legible fonts (Sheedy et al., 2005). Left-aligned text improves task performance over justified text because the word spacing that is forced by justified text impairs readability (Ling and van Schaik, 2007). Labels should be placed close to their corresponding graphic objects (modeling symbols) to reduce the cognitive resources that would be required to scan and search the model (Wagemans et al., 2012). Based on the Gestalt law of common region, "the tendency for elements that lie within the same bounded area to be grouped together" (Palmer, Brooks and Nelson, 2003, p. 312), placement of labels inside modeling symbols has been proposed as the best solution (Moody, 2012).

Paper 1: Figl, Kathrin (2017). User Evaluation of Symbols for Core Business Process Modeling Concepts. 25th European Conference of Information Systems (ECIS). Guimarães, Portugal.

The paper "User Evaluation of Symbols for Core Business Process Modeling Concepts" (Figl, 2017b) continued this line of research. (Other results from this paper were described in section 5.1.1.) I empirically tested the modeling guideline that labels should be placed inside symbols (Koschmider, Figl and Schoknecht, 2015; Moody, 2012). UML, EPC, and BPMN symbols typically place the label inside the task symbol (a rectangle), whereas YAWL places it beside the rectangle. However, I was not able to validate this guideline, as the quality of the YAWL task symbols was not rated less favorably by the participants than the other versions of task symbols. Perhaps placing a label beside a symbol is sufficient for perceiving symbol and text as a unit, as the Gestalt law of proximity suggests, and following the Gestalt law of common region is unnecessary.

8 Model Characteristics

Identifying and addressing cognitive difficulties in comprehending models based on model characteristics can make it possible to manage a model's cognitive load. For instance, model tool designers can provide syntax highlighting of difficult model structures and warn modelers when their models exceed a certain threshold of complexity.

Researchers have used a variety of metrics to measure and operationalize models' structural complexity and properties (Mendling 2013). Aguilar et al. (2008) distinguished between "base" measures, which count the model's most significant elements, and "derived" measures, which provide the proportions between the model's elements. In the context of process modeling, Mendling (2012a) categorized metrics into five categories: size measures, connection, modularity, gateway interplay, and complex behavior. My literature review on process model comprehension (Figl, 2017a) built on this categorization and integrated it with other terms: size measures, connection, modularity/structuredness, gateway interplay/control structures, and syntax rules. In the context of my habilitation, I conducted experiments in the area of process modeling that were related to the categories of modularity/structuredness and gateway interplay/control structures (Figl and Laue, 2015), as well as experiments in software variability modeling (Reinhartz-Berger and Figl, 2014; Reinhartz-Berger, Figl and Haugen, 2014) to identify model metrics that may be central to the cognitive load when users interact with these models. The results of these studies also added insights to the human understanding of fundamental ideas of the computer science discipline (Zendler and Spannagel, 2008), as process logic concepts (notably parallel execution, loops and decisions) and concepts used in variability modeling (OR, XOR) and hierarchical structuring (decomposition and classification, abstraction and modularization) represent subsets of humans' "computational thinking" (Wing, 2008).

8.1 Process Model Characteristics

Journal Article 5: Figl, Kathrin, & Laue, R. (2015). Influence Factors for Local Comprehensibility of Process Models. International Journal of Human-Computer Studies, 82, 96-110.

In the article "Influence Factors for Local Comprehensibility of Process Models" (Figl and Laue, 2015) we developed a research model to capture the influence of two effects on the cognitive difficulty of deductive reasoning tasks based on process models: (i) the presence of different types of control-flow patterns (such as conditional or parallel execution) in a process model and (ii) the interactivity of model elements. We focused on open research questions concerning metrics related to modularity/structuredness (interactivity between model elements, measured with the presence of cut-vertices and the process structure's tree distance) and gateway interplay/control structures. The analyses were based on sixty-one reasoning tasks undertaken by 155 modelers. Rather than the task's wording, we used qualitative coding of the control-flow patterns that must be understood in order to answer a comprehension task correctly.

The results from this study indicate that the presence of certain control-flow patterns (order/sequence, concurrency/AND, exclusiveness/XOR, repetition/loop and compound, measured for each comprehension task) influences the cognitive difficulty of reasoning tasks. Tasks were most difficult if they demanded that the reader understand repetition, and compound control-flow patterns (a combination of at least two patterns other than order), concurrency, and exclusiveness followed in difficulty. Tasks for which only the control-flow pattern order had to be understood had the highest comprehension accuracy. There was also a trendwise effect on subjective difficulty, as compound patterns were more difficult than order, concurrency, or exclusiveness, and repetition was more difficult than order.

The findings supported the prediction that the higher the interactivity between model elements, measured via the process structure's tree (PST) distance metric (PST distance between two elements A and B = the number of arcs between A and B in the PST minus on), the lower the comprehension accuracy and the higher the perceived difficulty. However, another metric of interactivity—the presence of cut-vertices such that the presence of a single arc in the BPM separates the BPM into two disjointed parts—was not related to cognitive difficulty.

The work was an extension of the extant literature, which has predominantly looked at global metrics and process models' understandability. By investigating the local comprehensibility of model structures' properties, the study shed light on what makes it difficult for humans to reason based on a process model. Our results also help to clarify possible comprehension problems in process models and can guide modeling tool developers in providing adequate feedback on the cognitive difficulty of model parts.

8.2 Feature Model Characteristics

Paper 3: Reinhartz-Berger, I., Figl, Kathrin, Haugen, Ø (2014). Comprehending Feature Models Expressed in CVL. 17th ACM/IEEE International Conference on Model-Driven Engineering Languages and Systems (MODELS), Valencia, Spain, Springer International Publishing: 501-517.

The main aim of the paper "Comprehending Feature Models Expressed in CVL" (Reinhartz-Berger, Figl and Haugen, 2014) was to shed light on difficulties in understanding feature models that are expressed in CVL. Using an experimental approach with participants who were either familiar or unfamiliar with feature modeling (n=38), we analyzed comprehensibility in terms of comprehension score, time spent to complete tasks, and perceived difficulty of different feature-modeling constructs. (Section 10.1.3 summarized the study's results concerning familiarity of participants.) Our results showed that OR relationships are especially difficult to understand, even for trained users. Research findings on deductive reasoning with natural language connectives provided a theoretical explanation for the high cognitive difficulty of inclusive ORs. "OR" is likely to be misinterpreted in its exclusive form, not as an inclusive OR-operator (Naess, 1961). Based on empirically detected comprehension difficulties, other model domains' modeling guidelines have advised avoiding inclusive OR gateways altogether (Mendling, Reijers and van der Aalst, 2010). While this option is not feasible for the area of feature modeling, our results can be used to adapt training material and to warn modeling practitioners to be cautious in the use of OR relationships.

Paper 2: Reinhartz-Berger, I., Figl, Kathrin (2014). Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM. 18th Software Product Line Conference, Florence, Italy: ACM. **(Best Paper Award)**	

In the paper "Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM" (Reinhartz-Berger, Figl and Haugen, 2014) we examined the comprehensibility of variability models and their relationships to development artifacts for novice users. (The main results concerning modeling notation were presented in section 5.1.3.) Questions related to optional and mandatory elements were the easiest to comprehend and to answer correctly, followed by questions related to OR/XOR relationships and constraints. Questions that referred to relationships to the base model were the most difficult. Participants spent the most time in solving questions on relationships to base models, followed by OR/XOR relationships, constraints and optional/mandatory elements. Overall, the results showed high comprehensibility of the variability models but low comprehensibility of the relationships between the variability models and the development artifacts (UML class models). This result pinpointed the high cognitive difficulty of cognitively integrating information from multiple models, perhaps because of a split-attention effect (Zugal et al., 2011). Therefore, we encouraged the use of appropriate visual cues that show which model elements belong to each other in order to support users' cognitive integration processes.

The result that optional/mandatory elements are the easiest to answer could have occurred because they resemble binary relationships, while OR/XOR relations involve at least three elements. Based on the cognitive load theory (Sweller, 1988), a higher number of elements that require attention increases the cognitive load, resulting in greater comprehension difficulty.

9 Task Characteristics

Cognitive load in human interaction with a conceptual model is also influenced by the task setting. In the context of the habilitation, I investigated task settings in the domain of business process modeling.

One of my studies investigated user preferences for diagrammatic process models in various task settings in terms of understanding the process, communicating the process to someone who is unfamiliar with it, supporting developers of an IT-based system in executing the process and identifying opportunities to improve how the process being executed (Figl and Recker, 2016a). The results of this study were summarized in section 5.3.1.

Comprehension performance in an experiment varies based on the questions asked (Melcher et al., 2010) and the kind and amount of assistance given (e.g., Soffer, Wand and Kaner, 2015). The task characteristics that capture to which elements in a model a task is related were discussed in sections 8.1 and 8.2. I also investigated the effects of the validity of comprehension tasks and the wording of the tasks on cognitive difficulty, the results of which are presented in the next sections.

9.1 Validity of Comprehension Tasks

Journal Article 5: Figl, Kathrin, & Laue, R. (2015). Influence Factors for Local Comprehensibility of Process Models. International Journal of Human-Computer Studies 82, 96-110.

The study presented in the article "Influence Factors for Local Comprehensibility of Process Models" (Figl and Laue, 2015) indicated that invalid statements on a process model were easier to identify than valid statements were, probably because only one falsifying argument must be found to identify an invalid statement. (The main results of this study were presented in section 8.1.) This explanation is in line with research that has shown that falsification strategies are especially relevant to the ability to achieve insight into a reasoning task (Johnson-Laird and Wason, 1970). One suggestion based on this finding is that providing additional information on the most important constraints and invalid process execution options in a process model could improve comprehension.

9.2 Wording of Comprehension Tasks

Paper 7: Figl, Kathrin, Laue, R. (2011). Cognitive Complexity in Business Process Modeling. 23rd International Conference on Advanced Information Systems Engineering (CAISE). Lecture Notes in Computer Science, Volume 6741/2011, 452-466.

The paper "Cognitive Complexity in Business Process Modeling" (Figl and Laue, 2011) addressed the wording of comprehension tasks. To allow for empirical assessment of the wording of the comprehension tasks, we systematically constructed model sets and comprehension questions. We used two wordings per type of comprehension question (concurrency, exclusiveness, order, repetition) on pairs of activities, which were either close (one activity between the activities) or distant (more than one activity between the activities).

The results of an empirical study with 199 students suggested that comprehension questions on order and concurrency were easier to answer than were those on repetition and exclusiveness. While task wording had only a trendwise effect on the percentage of correct answers, its effect on perceived difficulty was significant. Order tasks were the easiest and had the lowest subjective difficulty, followed by concurrency tasks. Exclusiveness tasks were the most difficult in terms of comprehension accuracy, and participants rated repetition tasks the most difficult overall.

Implications of these results for researchers include exercising caution when aggregating the answer rates to randomly chosen comprehension questions into total comprehension measures for models. As the choice of questions might significantly influence comprehension scores, selection and construction of questions should be balanced.

10 User Characteristics

Modeler expertise is an individual-level variable that affects human interaction with models. Petre (1995, p. 34) claimed that "experts 'see' differently and use different strategies." Experts develop schemas–language-independent, abstract problem representations–of modeling constructs in their minds, as has been demonstrated in such related disciplines as programming (Rist, 1989). In so doing, experts leave more working memory resources available for interacting with the model.

Against this background, I included a variety of user characteristics in my studies, including experience, familiarity and knowledge, cognitive style and individual creativity. Most of my studies will be mentioned for a second time because user-related variables were collected as control variables in these studies. In some of my studies, homogenous groups of participants (e.g., students) were chosen, and user characteristics like domain knowledge were held constant to avoid bias from high levels of familiarity with the domain in the experiments and to render unlikely an effect on the dependent variables (e.g., model comprehension). However, during my habilitation I also conducted studies in which user characteristics like cognitive style (Figl and Recker, 2016a) and individual creative competence (Figl and Recker, 2016c; Figl and Weber, 2011, 2012) were the main variables of interest.

10.1 Modeling Experience, Familiarity and Knowledge

10.1.1 Effect on Preferences for Process Representations

Journal Article 3: Figl, Kathrin, & Recker, J. (2016). Exploring Cognitive Style and Task-Specific Preferences for Process Representations. Requirements Engineering, 21(1), 63-85.

In the study on user preferences for process representations presented in the article "Exploring Cognitive Style and Task-Specific Preferences for Process Representations" (Figl and Recker, 2016a), we recruited university students from a business school as study subjects, following recommendations about sample selection (Compeau et al., 2012). (Main results of this study were discussed in section 5.3.1.) The high levels of knowledge, experience and formal training in model design that is typically found in experienced modelers would have induced a significant bias because of the likelihood of an established preference for a particular representation format. Therefore, the variance of process modeling experience (the number of models created or read) in our novice sample was low and the varianot correlated with any of the dependent measures.

We also used a conceptual modeling test to measure conceptual modeling knowledge. Participants were shown several conceptual models and were asked to identify the models' type from a list of choices. Knowledge about conceptual modeling heightened the participants' preference for a process model representation over structured text for comprehension tasks.

10.1.2 Effect on Comprehension of Process Models

Mendling et al.'s (2012) process modeling knowledge test is widely used to assess process modeling knowledge (Figl, 2017a), and I have used it to find a positive effect of process modeling knowledge on comprehension accuracy (Figl and Laue, 2015; Figl, Recker and Mendling, 2013; Figl and Strembeck, 2015), on perceived cognitive load (Figl and Laue, 2015; Figl, Mendling and Strembeck, 2013; Figl, Recker and Mendling, 2013) and on the subjective difficulty of control-flow comprehension (Figl, Recker and Mendling, 2013), and no effect of process modeling knowledge on time (Figl, Mendling and Strembeck, 2013; Figl, Recker and Mendling, 2013; Figl and Strembeck, 2015) or perceived ease of use of the model (Figl and Strembeck, 2015). Only the study presented in (Figl, Mendling and Strembeck, 2013) reported that prior knowledge about process modeling had no significant effect on comprehension accuracy, perhaps because other, intercorrelated control variables that measured experience with process modeling (e.g., training on modeling basics) were included in the analyses.

Moreover, modelers with more process modeling knowledge performed better and rated the subjective difficulty of loops lower than did modelers with lower process modeling knowledge (Figl and Laue, 2015). This result leads to conclusions on how to teach business process modeling, such as that non-trivial models with loops should be discussed. Training on modeling basics at a university or school has also been shown to have a significant positive effect on comprehension accuracy and subjective cognitive load (Figl, Mendling and Strembeck, 2013).

An important contribution of reviewing the literature's results on user characteristics is to ease the selection of variables for future researchers. Overall, future studies on process model comprehension should use Mendling et al.'s (2012) process modeling knowledge test to control for individual variations in knowledge.

10.1.3 Effect on Comprehension of Software Feature Models

Paper 3: Reinhartz-Berger, I., Figl, Kathrin, Haugen, Ø (2014). Comprehending Feature Models Expressed in CVL. 17th ACM/IEEE International Conference on Model-Driven Engineering Languages and Systems (MODELS), Valencia, Spain, Springer International Publishing: 501-517.

The study presented in the paper "Comprehending Feature Models Expressed in CVL" (Reinhartz-Berger, Figl and Haugen, 2014) found a positive association between familiarity and feature model comprehension scores based on thirty-eight participants. Participants who were familiar with feature modeling achieved an average comprehension score of 85 percent, while unfamiliar participants achieved an average score of 69 percent.

Familiarity also had a significant influence on time. Contrary to our expectations, participants who were familiar with feature modeling took more time to complete tasks, perhaps because they were more motivated to solve—and more interested and involved in solving—the comprehension tasks correctly.

While participants who were familiar with feature modeling achieved an average comprehension score of 90 percent on questions that involved constraints, unfamiliar participants achieved an average score of 67 percent on these questions. The difference in the scores on questions that did not involve constraints was smaller, indicating that familiar modelers understood constraints significantly better than unfamiliar modelers did. Basic elements—mandatory, optional, and alternative (XOR) features—were rated significantly more difficult by participants that had no prior experience with feature models than they were by experienced modelers, and OR relationships were perceived as difficult regardless of the familiarity level. Overall, the results showed that familiar modelers had less trouble with comprehension and saw the tasks as less difficult than unfamiliar modelers did. This result is in line with Recker and Dreiling (2007), who showed that familiarity with models in a specific domain enables modelers to understand a new modeling language in that domain faster than others can and with less effort.

Our study, presented in Reinhartz-Berger, Figl and Haugen (2017) was based on an experiment with ninety participants. Discussed in section 6.3, the study used the same familiarity measure as the study presented in Reinhartz-Berger, Figl and Haugen (2014) and revealed similar results. Familiarity with feature modeling had an effect on all dependent variables: Participants with greater familiarity rated the model's perceived ease of use higher and the difficulty in understanding model elements lower. They performed better in the comprehension tasks, but they also took more time to solve them.

10.2 Individual Creativity and Process Model Redesign

Designing business processes creatively is an important requirement for implementing process-aware information systems, so another aim of my research was to determine the influence of a creative personality on process (model) redesign. Being able to identify individual creative potential for redesign tasks is relevant to, for example, assembling effective teams.

Paper 14: Figl, Kathrin, Weber, B. (2011). Creative Personality and Business Process Redesign. 4th International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA), Hamburg, Germany, Lecture Notes in Informatics 190 GI, 189-194.

The purpose of the paper "Creative Personality and Business Process Redesign" (Figl and Weber, 2011) was to discuss the influence of a creative personality on process redesign. Building on creativity theories from the field of cognitive psychology, we identified important individual factors in performing effective process redesign and hypothesized their contributions to creative process design using a modeling tool.

Paper 5: Figl, Kathrin, Weber, B. (2012). Individual Creativity in Designing Business Processes. Advanced Information Systems Engineering Workshops. Lecture Notes in Business Information Processing. Volume 112, 294-306. Berlin: Springer.

The research model in Figl and Weber (2011) was tested empirically in a study presented in the paper "Individual Creativity in Designing Business Processes" (Figl and Weber, 2012). The latter study investigated how process modeling competence and individual creativity style and competence influence creativity in a business process redesign task. We explored these relationships by means of a laboratory experiment with forty-eight business students using the Cheetah Experimental Platform (Pinggera, Zugal and Weber, 2010). Cheetah guides participants through a variety of questions and offers a process-modeling tool that logs every modeling action (e.g., adding and deleting activities) to facilitate later analysis. We content-coded process redesign ideas into semantic categories in order to determine the breadth (number of semantic categories according to content categorization) and depth (average number of ideas per semantic category) of creative production.

Our results showed that work experience with process models positively correlates with originality and innovativeness but not with the other indicators of creative redesign (fluency, breadth and depth of creative production). In addition, the number of process models read or created correlated positively with originality and with the innovativeness and depth of creative production, and tended to correlate with the fluency and breadth of creative production. While process modeling experience was positively associated with the creative quality of a business process redesign, individual creativity style and competence, measured by the verbal subtest of the Abbreviated Torrance Test for Adults (Clapham, 2004), seemed to have little effect. The findings underscored the importance of training in process modeling to enable employees to realize their full creative potential when redesigning process models in process improvement projects.

Journal Article 4: Figl, Kathrin, & Recker, J. (2016). Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams. Information & Management, 53(6), 767–786.

Based on findings in the literature on how individual characteristics relate to creative problem-solving, the research model used in the process innovation experiment in Figl and Recker (2016b) used creative attitude and creative competence to acknowledge the relevance of the individual as a creative person to creative design solutions. Other results of this experiment were presented in section 5.3.2.

We used the “preference for ideation” scale (Basadur and Finkbeiner, 1985) to measure creative attitude, a scale that measured the tendency to evaluate ideas prematurely, and the items from Davis et al. (1992) to measure intrinsic motivation to perform the process re-design activities. However, creative attitudes did not have a significant linear correlation with any of the dependent measures.

We measured creative competence using a standardized instrument, the Abbreviated Torrance Test for Adults (with a verbal and figural subtest) (Clapham, 2004), which measures individuals’ creative thinking competence in terms of fluency (number of ideas), originality (unusualness of ideas) and elaboration (embellishment of ideas with details). The results of the study showed that, while the individual’s creative competence had no effect on appropriateness, originality and impact of ideas, it did affect the number of ideas produced. These results agree with findings in Figl and Weber (2012), where creative competence also had no effect on the creative quality of process redesigns. Overall, the results confirmed the widely held belief that more creative participants produce more ideas.

10.3 Cognitive Style and Preferences for Process Representations

Journal Article 3: Figl, Kathrin, & Recker, J. (2016). Exploring Cognitive Style and Task-Specific Preferences for Process Representations. Requirements Engineering, 21(1), 63-85.

In the article “Exploring Cognitive Style and Task-Specific Preferences for Process Representations” (Figl and Recker, 2016a) we studied the preference for various forms of process model representation based on the user’s cognitive style and the task setting. (Results concerning the task setting were described in 5.3.1.) We used Blazhenkova and Kozhevnikov’s (2009) validated instrument to measure the three levels of cognitive style—spatial, object and verbal—following those authors’ object-spatial-verbal cognitive style model. We were the first to examine the influence of individual cognitive style on the decision to use process models, thereby collecting further evidence for cognitive processing activities in process modeling. Our results suggest that, while users tend to prefer diagrammatic forms of representation, preferences vary significantly based on cognitive style.

Verbal style lowered the preference for diagrams over structured text and heightened the preference for structured text over text. Spatial style heightened the preference for diagrams over text. These findings suggest that diagrams’ externalized representations can be effective for those whose cognitive styles do not align with highly verbalized representations but who instead prefer the visual support of structural elements (e.g., via shapes and lines). Previous research has indicated that process diagrams can assist users in building of mental models better than text can because the visual structure of process diagrams' elements is similar to the internal structure of a mental model of procedures (Glenberg and Langston, 1992). Our research developed this argument further by showing that preferences for certain forms of representation are at least partially dependent on the individual's cognitive processing style. Diagrammatic representations apparently provide a superior fit for individuals who prefer internal imagery of mental models.

These results can help to improve the alignment of individual cognitive styles and information aids in the context of process-related projects, thereby contributing to increased work satisfaction among employees.

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12 Appendix

A. Overview of Variables Investigated in the Habilitation Thesis

Table 5. Overview of Independent and Dependent Variables Investigated in the Articles Submitted for the Habilitation

Category of Independent Variables	Dependent Variables (in empirical studies)
Representation Paradigm	
process model representation: text, structured text, diagram (BPMN); icon use: with and without icons (Figl and Recker, 2016a)	preference for a process representation for four tasks: • understanding the process • communicating the process to someone who is unfamiliar with its procedures • supporting developers of an IT-based system in executing the process • identifying opportunities to improve how the process is executed
process model representation: text, structured text, diagram (BPMN) (Figl and Recker, 2016b)	creativity in process redesign: fluency, originality, appropriateness and impact of ideas; type of idea (control flow-/information system-/data-/technological resources-related ideas)
Primary Notation	
process modeling notations: BPMN, UML AD, BPMN, YAWL, EPCs, Petri nets (Figl, Mendling and Strembeck, 2009)	theoretical discussion of semiotic clarity, perceptual discriminability, semantic transparency, graphic economy and visual expressiveness of notational symbols
process modeling notations: focus on routing symbol design (BPMN, UML AD, BPMN, YAWL, EPCs) (Figl et al., 2010b)	theoretical discussion of semiotic clarity, perceptual discriminability, semantic transparency, graphic economy and visual expressiveness of routing symbols
process modeling notations: BPMN, UML AD, YAWL, EPCs (Figl, Mendling and Strembeck, 2013)	model comprehension: comprehension accuracy, comprehension efficiency (time taken), comprehension accuracy, subjective rating of cognitive load
process modeling notations: BPMN, UML AD, YAWL (Figl, 2012)	memory tasks: verbal and visual recall
decision model and notation (DMN) (Dangarska, Figl and Mendling, 2016)	theoretical discussion
software feature/variability modeling notations: CVL vs. OVM (Reinhartz-Berger and Figl, 2014)	comprehension accuracy, comprehension efficiency (time taken), perceived comprehension difficulty, user ratings of learning difficulty, model comprehensibility and preference for CVL vs. OVM
instructional design notations: E^2ML, PoEML, coUML (Figl et al., 2010a)	user ratings of • semiotic clarity (absence of construct deficits and excess constructs) • graphic economy (number of different symbols) • perceptual discriminability • visual expressiveness • dual coding • semantic transparency

Category of Independent Variables	Dependent Variables (in empirical studies)
	• perceived usefulness
Notational Characteristics	
deficiencies in semiotic clarity and perceptual discriminability (Figl, Mendling and Strembeck, 2013)	comprehension accuracy, comprehension efficiency (time taken), subjective rating of cognitive load
user evaluation of symbols - perceptual discriminability, semantic transparency, perceptual pop-out of symbols, symbol aesthetics (Figl, Recker and Mendling, 2013)	comprehension accuracy, comprehension efficiency (time taken), subjective rating of cognitive load, perceived difficulty in comprehending control flow
Secondary Notation	
(process) model layout: direction (flow) (Figl and Strembeck, 2014)	theoretical discussion
(process) model layout: direction (flow) (Figl and Strembeck, 2015)	comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of the model
visualization of (business process) model hierarchies (model decomposition) (Figl, Koschmider and Kriglstein, 2013)	perceived usefulness, preference ratings
modeling style (for software feature models): hierarchical style vs. constrained style (Reinhartz-Berger, Figl and Haugen, 2017)	**comprehension:** comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of the model, subjective difficulty of the model **model creation:** selection of modeling style for two modeling situations after being exposed to one of the styles, model correctness, subjective difficulty
Label	
label design (Koschmider, Figl and Schoknecht, 2015)	theoretical discussion
label semantics: abstract versus concrete labels (Figl and Strembeck, 2015)	comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of the model
Model Characteristics	
modularity and structuredness of process models: element interactivity (of the activities included in a comprehension task) measured by the process structure tree distance and the existence of a cut vertex (Figl and Laue, 2015)	comprehension accuracy, subjective rating of cognitive load
control structures in process models: control flow structures (sequence versus loops versus concurrency (AND), XOR) per task measured by expert ratings for each comprehension task (Figl and Laue, 2015)	comprehension accuracy, subjective rating of cognitive load
semantic construct types in software feature/variability models: mandatory/optional features, XOR/ OR, relations to the base model (Reinhartz-Berger, Figl and Haugen, 2014)	comprehension accuracy, comprehension efficiency (time taken), and participants' perception of difficulty of different CVL model elements
semantic construct types in software feature/variability models: mandatory/optional features, XOR/ OR, relationship to the base model (Reinhartz-Berger and Figl, 2014)	comprehension accuracy, comprehension efficiency (time taken), perceived comprehension difficulty

Category of Independent Variables	Dependent Variables (in empirical studies)
choice dependency in software feature/variability models (Reinhartz-Berger, Figl and Haugen, 2017)	**comprehension:** comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of the model, subjective difficulty of the model **model creation:** selection of modeling style for two modeling situations after being exposed to one of the styles, model correctness, subjective difficulty
Task	
task setting: • understanding the process • communicating the process to someone who is unfamiliar with its procedures • supporting developers of an IT-based system in executing the process • identifying opportunities to improve how the process is executed (Figl and Recker, 2016a)	preference for using different process representations (text, structured text, diagram (BPMN); with/without icons) for different tasks
validity of statements in comprehension tasks (Figl and Laue, 2015)	comprehension accuracy, subjective rating of cognitive load
wording of comprehension tasks: control flow structures (sequence, loops, concurrency (AND), XOR) (Figl and Laue, 2011)	comprehension accuracy, subjective rating of cognitive load
User	
experience: training on modeling basics at a university or school (Figl, Mendling and Strembeck, 2013)	comprehension accuracy, comprehension efficiency (time taken), subjective rating of cognitive load
experience: work experience with process models (Figl and Weber, 2012)	creativity in process redesign: originality, innovativeness, fluency, breadth and depth of creative production
experience: the number of process models read or created (Figl and Weber, 2012)	creativity in process redesign: originality, innovativeness, fluency, breadth and depth of creative production
familiarity: familiarity with conceptual models (Figl and Recker, 2016a)	preference for a process representation for four tasks: • understanding the process • communicating the process to someone who is unfamiliar with its procedures • supporting developers of an IT-based system in executing the process • identifying opportunities to improve how the process is executed
familiarity: familiarity with UML class diagrams, three items based on the modeling-grammar familiarity scale from Recker (2010) (Reinhartz-Berger and Figl, 2014)	comprehension accuracy, comprehension efficiency (time taken), and participants' perception of the difficulty in comprehending CVL model elements
familiarity: familiarity with feature diagrams, three items based on the modeling-grammar familiarity scale from Recker (2010) (Reinhartz-Berger, Figl and Haugen, 2014)	comprehension accuracy, comprehension efficiency (time taken), and participants' perception of the difficulty in comprehending CVL model elements
familiarity: familiarity with feature diagrams, three items based on the modeling grammar familiarity scale from Recker (2010) (Reinhartz-Berger, Figl and Haugen, 2017)	comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of the model, subjective difficulty of the model

Category of Independent Variables	Dependent Variables (in empirical studies)
modeling knowledge: process modeling knowledge test score (Figl, Mendling and Strembeck, 2013)	comprehension accuracy, comprehension efficiency (time taken), subjective rating of cognitive load
modeling knowledge: process modeling knowledge test score (Figl and Laue, 2015)	comprehension accuracy, subjective rating of cognitive load
modeling knowledge: process modeling knowledge test score (Figl, Recker and Mendling, 2013)	comprehension accuracy, comprehension efficiency (time taken), subjective rating of cognitive load, perceived difficulty in comprehending control flow
modeling knowledge: process modeling knowledge test score (Figl and Weber, 2012)	creativity in process redesign: originality, innovativeness, fluency, breadth and depth of creative production
modeling knowledge: process modeling knowledge test score (Figl and Strembeck, 2015)	comprehension accuracy, comprehension efficiency (time taken), perceived ease of use of model
knowledge of class diagrams measured with three comprehension questions on a simple class diagram (Reinhartz-Berger and Figl, 2014)	comprehension accuracy, comprehension efficiency (time taken), and participants' perception of the difficulty in comprehending CVL model elements
conceptual modeling knowledge measured with a conceptual modeling test (recognizing notations test) (Figl and Recker, 2016a)	preference for a process representation for four tasks: • understanding the process • communicating the process to someone who is unfamiliar with its procedures • supporting developers of an IT-based system in executing the process • identifying opportunities to improve how the process is executed
participants' object-spatial-verbal cognitive style model from Blazhenkova and Kozhevnikov (2009), measured with their instrument (Blazhenkova and Kozhevnikov, 2009) (Figl and Recker, 2016a)	preference for a process representation for four tasks: • understanding the process • communicating the process to someone who is unfamiliar with its procedures • supporting developers of an IT-based system in executing the process • identifying opportunities to improve how the process is executed
creative competence measured with the Abbreviated Torrance Test for Adults (Goff and Torrance, 2002) (Figl and Recker, 2016b)	creativity in process redesign: fluency, originality, appropriateness and impact of ideas; type of idea (control flow-/information system-/data-/technological resources-related ideas)
creative attitudes (Figl and Recker, 2016b)	creativity in process redesign: fluency, originality, appropriateness and impact of ideas; type of idea (control flow-/information system-/data-/technological resources-related ideas)
creative personality style and creative competence (Figl and Weber, 2012)	creativity in process redesign: originality, innovativeness, fluency, breadth and depth of creative production

B. Journal List of the Department of Information Systems and Operations

Version: June 16, 2015

The seven journals in which I have published are marked in gray.

Table 6. Journal List of the Department of Information Systems and Operations

ISSN	Journal
0360-0300	ACM Computing Surveys
1532-0936	ACM SIGMIS Database
1529-3785	ACM Transactions on Computational Logic (TOCL)
1073-0516	ACM Transactions on Computer-Human Interaction
0362-5915	ACM Transactions on Database Systems
1557-7406	ACM Transactions on Information and System Security
1046-8188	ACM Transactions on Information Systems
2157-6912	ACM Transactions on Intelligent Systems and Technology
1556-4681	ACM Transactions on Knowledge Discovery from Data
2158-656X	ACM Transactions on Management Information Systems
0164-0925	ACM Transactions on Programming Languages and Systems
1557-7392	ACM Transactions on Software Engineering and Methodology
1559-1131	ACM Transactions on the Web
1741-1629	ALT-J: Research in Learning Technology
0254-5330	Annals of Operations Research
0004-3702	Artificial Intelligence
1469-297X	Assessment and Evaluation in Higher Education
1573-7535	Automated Software Engineering
1467-8535	British Journal of Educational Technology
1867-0202	Business & Information Systems Engineering (BISE) (früher: Wirtschaftsinformatik WI)
1052-150X	Business Ethics Quarterly (BEQ)
1866-8658	Business Research (früher: BuR - Business Research)
1099-0836	Business Strategy and the Environment
0008-1256	California Management Review
0001-0782	Communications of the ACM (CACM)
0958-8221	Computer Assisted Language Learning: an international journal
1460-2067	Computer Journal
1389-1286	Computer Networks (Elsevier)
1573-7551	Computer Supported Cooperative Work (CSCW)
0360-1315	Computers and Education (Elsevier)
0360-8352	Computers and Industrial Engineering
0898-1221	Computers and Mathematics with Applications
0305-0548	Computers and Operations Research
0167-4048	Computers and Security
0747-5632	Computers in Human Behavior
0166-3615	Computers in Industry
0169-023X	Data & Knowledge Engineering
1540-5915	Decision Sciences
0167-9236	Decision Support Systems
0166-218X	Discrete Applied Mathematics
1042-1629	Educational Technology Research and Development (Springer)
1567-4223	Electronic Commerce Research and Applications (ECRA)
1019-6781	Electronic Markets (em)
1573-7616	Empirical Software Engineering
0301-4215	Energy Policy
1751-7583	Enterprise Information Systems
2192-4376	EURO Journal on Transportation and Logistics
1476-9344	European Journal of Information Systems (EJIS)
0377-2217	European Journal of Operational Research (EJOR)
0957-4174	Expert Systems with Applications

1936-6582	Flexible Services and Manufacturing Journal (FSM)
0952-1895	Governance
1572-9907	Group Decision and Negotiation
0018-9162	IEEE Computer
1089-7801	IEEE Internet Computing
1536-1268	IEEE Pervasive Computing
1949-3045	IEEE Transactions on Affective Computing
0018-9391	IEEE Transactions on Engineering Management
1041-4347	IEEE Transactions on Knowledge and Data Engineering
1939-1382	IEEE Transactions on Learning Technologies
1536-1233	IEEE Transactions on Mobile Computing
0098-5589	IEEE Transactions on Software Engineering
2168-2216	IEEE Transactions on Systems, Man, and Cybernetics: Systems
0740-817X	IIE Transactions
0378-7206	Information & Management
1471-7727	Information and Organization
0950-5849	Information and Software Technology (Elsevier)
0306-4379	Information Systems (IS)
1572-9419	Information Systems Frontiers
1365-2575	Information Systems Journal (ISJ)
1526-5536	Information Systems Research (ISR)
1369-118X	Information, Communication & Society (iCS)
1526-5528	INFORMS Journal on Computing (JOC)
1470-3300	Innovations in Education and Teaching International
0020-4277	Instructional Science
1049-4820	Interactive Learning Environments
1526-551X	Interfaces
1556-1615	International Journal of Computer-Supported Collaborative Learning
1086-4415	International Journal of Electronic Commerce (IJEC)
1750-6220	International Journal of Energy Sector Management
1095-9300	International Journal of Human Computer Studies
0268-4012	International Journal of Information Management
0219-6220	International Journal of Information Technology & Decision Making
0144-3577	International Journal of Operations & Production Management
0960-0035	International Journal of Physical Distribution & Logistics Management
0925-5273	International Journal of Production Economics
1366-588X	International Journal of Production Research
0263-7863	International Journal of Project Management
1096-7494	International Public Management Journal
0927-5940	International Tax and Public Finance
1096-7516	Internet and Higher Education
1476-9360	JORS. Journal of the Operational Research Society (früher: Operational Research Quarterly)
0278-4254	Journal of Accounting and Public Policy
0091-3367	Journal of Advertising
1740-1909	Journal of Advertising Research JAR
0021-9010	Journal of Applied Psychology
1076-9757	Journal of Artificial Intelligence Research
1099-0771	Journal of Behavioral Decision Making
0044-2372	Journal of Business Economics (JBE) (früher: Zeitschrift für Betriebswirtschaft ZfB)
0167-4544	Journal of Business Ethics
0735-3766	Journal of Business Logistics
0148-2963	Journal of Business Research
0959-6526	Journal of Cleaner Production
1460-2466	Journal of Communication
1460-1559	Journal of Computational Finance
1365-2729	Journal of Computer Assisted Learning
1083-6101	Journal of Computer-Mediated Communication (JCMC)
1057-7408	Journal of Consumer Psychology

0093-5301	Journal of Consumer Research
1246-0125	Journal of Decision Systems
0165-1889	Journal of Economic Dynamics & Control
1069-4730	Journal of Engineering Education
1099-131X	Journal of Forecasting
1572-9397	Journal of Heuristics
1088-1980	Journal of Industrial Ecology
0165-5515	Journal of Information Science
0888-7985	Journal of Information Systems
1466-4437	Journal of Information Technology
1469-1930	Journal of Intellectual Capital
1520-6653	Journal of Interactive Marketing
1869-0238	Journal of Internet Services and Applications
1367-3270	Journal of Knowledge Management
1533-7928	Journal of Machine Learning Research
1557-1211	Journal of Management (JOM)
0742-1222	Journal of Management Information Systems
1056-4926	Journal of Management Inquiry
1467-6486	Journal of Management Studies (JMS)
0022-2429	Journal of Marketing
0022-2437	Journal of Marketing Research
0272-6963	Journal of Operations Management
1540-5885	Journal of Product Innovation Management (JPIM)
1053-1858	Journal of Public Administration Research and Theory
0047-2727	Journal of Public Economics
1478-4092	Journal of Purchasing & Supply Management
0022-4359	Journal of Retailing
0895-5646	Journal of Risk and Uncertainty
1094-6136	Journal of Scheduling
1059-0145	Journal of Science Education and Technology (Springer)
1523-2409	Journal of Supply Chain Management
0004-5411	Journal of the ACM (JACM)
1532-2890	Journal of the American Society for Information Science and Technology
1536-9323	Journal of the Association for Information Systems (JAIS)
1532-7809	Journal of the Learning Sciences
1570-8268	Journal of Web Semantics
0743-9156	JPP&M Journal of Public Policy & Marketing
0219-1377	Knowledge and Information Systems
1094-3501	Language Learning & Technology
0959-4752	Learning and Instruction (Elsevier)
0024-6301	Long Range Planning
0276-7783	Management Information Systems Quarterly (MISQ)
1526-5501	Management Science
1099-1468	Managerial and Decision Economics
1526-5498	Manufacturing & Service Operations Management (M&SOM)
0732-2399	Marketing Science
1432-5217	Mathematical Methods of Operations Research
0025-5610	Mathematical Programming
1526-5471	Mathematics of Operations Research
1540-1960	MIS Quarterly Executive
0894-069X	Naval Research Logistics
1461-4448	New Media & Society (NMS)
0899-7640	Nonprofit and Voluntary Sector Quarterly
1048-6682	Nonprofit Management & Leadership
0305-0483	Omega
1526-5463	Operations Research
0167-6377	Operations Research Letters
0171-6468	OR Spectrum

1059-1478	Production and Operations Management
0742-6046	Psychology & Marketing
0033-3298	Public Administration
0033-3352	Public Administration Review
0048-5853	Public Finance Review
1471-9037	Public Management Review
1432-010X	Requirements Engineering (Springer)
1863-6683	Review of Managerial Science
0162-2439	Science, Technology and Human Values
2210-4968	Semantic Web
1095-7111	SIAM Journal on Computing
0163-5808	SIGMOD Record
1552-8286	Social Science Computer Review
1619-1374	Software & Systems Modeling (Springer)
1097-0266	Strategic Management Journal (SMJ)
1359-8546	Supply Chain Management: An International Journal
1099-1727	System Dynamics Review
0040-1625	Technological Forecasting and Social Change
0963-8687	The Journal of Strategic Information Systems
0304-3975	Theoretical Computer Science
1475-3081	Theory and Practice of Logic Programming
0965-8564	Transportation Research Part A: Policy and Practice
0191-2615	Transportation Research Part B: Methodological
1361-9209	Transportation Research Part D: Transport and Environment
1366-5545	Transportation Research Part E: Logistics and Transportation Review
0041-1655	Transportation Science
1573-1391	User Modeling and User-Adapted Interaction (Springer)
1066-8888	VLDB Journal
0957-8765	Voluntas: International Journal of Voluntary and Nonprofit Organizations
1573-1413	World Wide Web (Springer)
0341-2687	zfbf Schmalenbachs Zeitschrift für betriebswirtschaftliche Forschung - Schmalenbach Business Review

C. Habilitation Guideline of the Department of Information Systems and Operations

Habilitationsrichtlinie des Departments Informationsverarbeitung und Prozessmanagement

Konkretisierung der Senatsrichtlinie

Juni 2015

In dieser Regelung wird die allgemeine Richtlinie des Senats für kumulative Habilitationen konkretisiert.

1. Eine Reihe

Für eine Sammelhabilitation werden mindestens fünf thematisch zusammenhängende sehr gute wissenschaftliche Beiträge erwartet, die in sehr guten wissenschaftlichen Publikationsorganen (siehe unten) publiziert wurden. Diese Zahl gilt als grober Richtwert und kann reduziert werden, wenn vom Habilitationswerber bahnbrechende wissenschaftliche Leistungen erzielt und publiziert wurden. Typischerweise handelt es sich bei den wissenschaftlichen Beiträgen um Journalartikel, diese können jedoch teilweise durch Beiträge in Proceedings erweitert werden. Vom Habilitationswerber werden zusätzlich weitere Publikationen und Vorträge auf einschlägigen Konferenzen, erwartet.

2. Sehr gute wissenschaftliche Beiträge

Als sehr gute wissenschaftliche Beiträge werden nur solche Publikationen gewertet, die ein entsprechendes wissenschaftliches Bewertungsverfahren durchlaufen haben, einen entsprechenden wissenschaftlichen Standard aufweisen und aus Sicht der jeweiligen (möglichst) internationalen Scientific Community einen großen wissenschaftlichen Erkenntnisfortschritt erbringen. Sie können interdisziplinärer Natur sein. Sie sollen mittel- oder langfristig, direkt oder indirekt einen Nutzen für Wirtschaft und Gesellschaft erwarten lassen.

3. Sehr gute Publikationsorgane

Eine vollständige und ständig aktualisierte Liste von Publikationsorganen, die von der Scientific Community als sehr gute Publikationsorgane eingestuft werden, existiert nicht und wird auch nicht angestrebt.

Die Liste der für sehr gut eingestuften Zeitschriften des Departments für Informationsverarbeitung und Prozessmanagement bildet eine Grundlage für entsprechende Publikationsorgane (Positiv-Liste). Diese Liste kann je nach Habilitationsschwerpunkt und angestrebter Venia durch weitere fachspezifische Zeitschriften ergänzt bzw. entsprechend eingeschränkt werden.

Der vierte und fünfte Artikel kann durch je drei Beiträge zu sehr guten Konferenzen substituiert werden. Sehr gute Konferenzen weisen folgende Eigenschaften auf:

- Die Beiträge werden einem wissenschaftlichen Auswahlprozess aus typischerweise drei oder mehr Peer-Reviews ausgewählt.
- Die Rückweisungsrate beträgt mehr als 70%
- Die Konferenzen werden von großen Fachgesellschaften (z.B. ACM, IEEE, IFIP, Usenix, AIS) veranstaltet.

Es wird erwartet, dass die Top-Konferenzen den Gutachtern bekannt sind, sodass diese die Eigenschaften selbständig überprüfen können.

4. Autorenschaft

Durch die wissenschaftlichen Publikationen sollte deutlich werden, dass der Habilitationswerber zur eigenständigen wissenschaftlichen Arbeit befähigt ist.

Mindestens ein Journalbeitrag sollte daher als Alleinautor publiziert werden. In den übrigen Aufsätzen sollte die fachinternationale übliche Autorenzahl (ca. zwei bis drei Autoren) nicht überschritten werden. Im Fall von vier oder mehr Autoren ist der eigene Beitrag vom Habilitationswerber eingehend zu begründen.

Bei darüber hinausgehenden Alleinpublikationen sind zwei Soloaufsätze wie drei Aufsätze in Co-Autorenschaft zu behandeln.

5. Zeitraum

Die fünf Aufsätze sollen in einem Zeitraum der letzten zehn Jahre akzeptiert worden sein. Ältere Aufsätze werden im Verhältnis eins zu drei abgewertet.

6. Übergangsregelung

Das Vertrauen der Habilitationswerber, die geltend machen können, dass sie sich auf die Geltung früherer Regelungen verlassen haben, ist zu schützen, sofern die Leistungen nicht früheren Regelungen im Geiste widersprechen.

7. Richtlinie nicht kumulative Habilitation (Monographie)

Auch diejenigen Habilitationswerber, die in Absprache mit ihrem Betreuer eine Monographie abfassen, sollten über diese hinaus Aufsätze in wissenschaftlichen Zeitschriften und geeigneten Fachkonferenzen veröffentlichen.

Im Unterschied zur kumulativen Habilitation genügt aber eine geringere Anzahl von Aufsätzen in Fachzeitschriften und/oder Konferenzbänden, die von der internationalen Scientific Community als sehr gute Publikationsorgane eingestuft werden. Obenstehende Spezifikationen sind analog anzuwenden.

D. Articles that Form the Cumulative Habilitation

Table 7 and Table 8 provide the order of the subsequent articles and papers of the cumulative habilitation. Reference labels were added to the first page of all conference publications.

Table 7. Journal Articles (and corresponding extended abstracts; the first seven journals are listed in the department's journal list)

Reference	Full Reference	Page
(Sole-Authored) Journal Article 1 (Figl, 2017a)	Figl, Kathrin (2017). Comprehension of Procedural Visual Business Process Models. **Business & Information Systems Engineering**, 59(1), 41-67	69
Extended Abstract 1 (Figl, 2017c)	Figl, Kathrin (2017). **Why are Process Models Hard to Understand? (Keynote)** Lecture Notes in Business Information Processing. 5th International Workshop on Cognitive Aspects of Information Systems Engineering – COGNISE'17 in Conjunction with CAiSE'17. Essen, Germany.	97
Journal Article 2 (Reinhartz-Berger, Figl and Haugen, 2017)	Reinhartz-Berger, I., Figl, Kathrin, & Haugen, Ø. (2017). Investigating Styles in Variability Modeling: Hierarchical vs. Constrained Styles. **Information and Software Technology**, 87, 81-102.	143
Journal Article 3 (Figl and Recker, 2016a)	Figl, Kathrin, & Recker, J. (2016). Exploring Cognitive Style and Task-Specific Preferences for Process Representations. **Requirements Engineering**, 21(1), 63-85.	165
Journal Article 4 (Figl and Recker, 2016b)	Figl, Kathrin, & Recker, J. (2016). Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams. **Information & Management**, 53(6), 767–786.	189
Extended Abstract 2 (Figl and Recker, 2016c)	Figl, Kathrin, & Recker, J. (2016). **Process Innovation as Creative Problem Solving: An Experimental Study of Textual Descriptions and Diagrams [Extended Abstract]**. International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA), Vienna, Austria.	209
Journal Article 5 (Figl and Laue, 2015)	Figl, Kathrin, & Laue, R. (2015). Influence Factors for Local Comprehensibility of Process Models. **International Journal of Human-Computer Studies**, 82, 96-110.	213
Extended Abstract 3 (Figl and Recker, 2016c)	Figl, Kathrin, & Laue, R. (2016). **Kognitive Belastung als lokales Komplexitätsmaß in Geschäftsprozessmodellen**. Software Engineering, Gesellschaft für Informatik (GI), Lecture Notes in Informatics (LNI),Vienna, Austria. [in German]	229

Reference	**Full Reference**	**Page**
Journal Article 6 (Figl, Mendling and Strembeck, 2013)	Figl, Kathrin, Mendling, J., & Strembeck, M. (2013). The Influence of Notational Deficiencies on Process Model Comprehension. **Journal of the Association for Information Systems**, 14(6), 312-338.	231
Journal Article 7 (Figl, Recker and Mendling, 2013)	Figl, Kathrin, Recker, J., & Mendling, J. (2013). A Study on the Effects of Routing Symbol Design on Process Model Comprehension. **Decision Support Systems**, 54(2), 1104-1118.	259
Journal Article 8 (Figl et al., 2010a)	Figl, Kathrin, Derntl, M., Rodriguez, M. C., & Botturi, L. (2010). Cognitive Effectiveness of Visual Instructional Design Languages. **Journal of Visual Languages & Computing**, 21(6), 359-373.	275

Table 8. Papers in Peer-Reviewed Conference Proceedings (the first eight papers appeared in conferences with an acceptance rate < 30% or at the ECIS)

Reference	**Full Reference**	**Page**
Paper 1 (Figl, 2017b)	Figl, Kathrin (2017). **User Evaluation of Symbols for Core Business Process Modeling Concepts**. 25th European Conference of Information Systems (ECIS). Guimarães, Portugal. (accepted)	291
Paper 2 (Reinhartz-Berger, Figl and Haugen, 2014)	Reinhartz-Berger, I., Figl, Kathrin (2014). **Comprehensibility of Orthogonal Variability Modeling Languages: The Cases of CVL and OVM**. 18th Software Product Line Conference, Florence, Italy: ACM. **(Best Paper Award)**	305
Paper 3 (Reinhartz-Berger and Figl, 2014)	Reinhartz-Berger, I., Figl, Kathrin, Haugen, Ø (2014). **Comprehending Feature Models Expressed in CVL**. 17th ACM/IEEE International Conference on Model-Driven Engineering Languages and Systems (MODELS), Valencia, Spain, Springer International Publishing: 501-517.	315
Paper 4 (Figl, Koschmider and Kriglstein, 2013)	Figl, Kathrin, Koschmider, A., Kriglstein, S. (2013). **Visualising Process Model Hierarchies**. European Conference of Information Systems (ECIS), Utrecht, The Netherlands.	333
Paper 5 (Figl and Weber, 2012)	Figl, Kathrin, Weber, B. (2012). **Individual Creativity in Designing Business Processes.** Advanced Information Systems Engineering Workshops. Lecture Notes in Business Information Processing. Volume 112, 294-306. Berlin: Springer.	347

Reference	Full Reference	Page
Paper 6 (Figl and Derntl, 2011)	Figl, Kathrin, Derntl, M. (2011). **The Impact of Perceived Cognitive Effectiveness on Perceived Usefulness of Visual Conceptual Modeling Languages.** 30th International Conference on Conceptual Modeling (ER 2011). Lecture Notes in Computer Science, Volume 6998/2011, Brussels, Belgium, 78-91.	361
Paper 7 (Figl and Laue, 2011)	Figl, Kathrin, Laue, R. (2011). **Cognitive Complexity in Business Process Modeling**. 23rd International Conference on Advanced Information Systems Engineering (CAISE). Lecture Notes in Computer Science, Volume 6741/2011, 452-466.	375
Paper 8 (Figl et al., 2010b)	Figl, Kathrin, Mendling, J., Strembeck, M. & Recker, J. (2010). **On the Cognitive Effectiveness of Routing Symbols in Process Modeling Languages.** Business Information Systems (BIS) 2010. Lecture Notes in Business Information Processing Volume 47. Berlin: Springer.	391
Paper 9 (Dangarska, Figl and Mendling, 2016)	Dangarska, Z., Figl, Kathrin, Mendling, J. (2016). **An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN).** IEEE 2nd International Workshop on Compliance, Evolution and Security in Intra- and Cross-Organizational Processes, Vienna, Austria.	403
Paper 10 (Koschmider, Figl and Schoknecht, 2015)	Koschmider, A., Figl, Kathrin, Schoknecht, A. (2015). **A Comprehensive Overview of Visual Design of Process Element Labels**. Business Process Management Workshops. Lecture Notes in Business Information Processing. Innsbruck, Austria.	413
Paper 11 (Figl and Strembeck, 2015)	Figl, Kathrin, Strembeck, M. (2015). **Findings from an Experiment on Flow Direction of Business Process Models**. International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA). Lecture Notes in Informatics (LNI), Innsbruck, Austria.	425
Paper 12 (Figl and Strembeck, 2014)	Figl, Kathrin, Strembeck, M. (2014). **On the Importance of Flow Direction in Business Process Models**. 9th International Conference on Software Engineering and Applications, Vienna, Austria: Scitepress.	441
Paper 13 (Figl, 2012)	Figl, Kathrin (2012). **Symbol Choice and Memory of Visual Models.** IEEE Symposium on Visual Languages and Human-Centric Computing (VL-HCC), Innsbruck, Austria. IEEE Computer Society, 97-100.	447
Paper 14 (Figl and Weber, 2011)	Figl, Kathrin, Weber, B. (2011). **Creative Personality and Business Process Redesign.** 4th International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA), Hamburg, Germany, Lecture Notes in Informatics 190 GI, 189-194.	451

Reference	Full Reference	Page
Paper 15 (Figl, Mendling and Strembeck, 2009)	Figl, Kathrin, Mendling, J. & Strembeck, M. (2009). **Towards a Usability Assessment of Process Modeling Languages.** GI-Workshop EPK 2009: Geschäftsprozessmanagement mit Ereignisgesteuerten Prozessketten. CEUR-WS: Berlin.	457