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ON THE THEORETICAL FOUNDATIONS OF RESEARCH INTO THE UNDERSTANDABILITY OF BUSINESS PROCESS MODELS

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Constantin Houy, Peter Fettke, and Peter Loos, 2014, "ON THE THEORETICAL FOUNDATIONS OF RESEARCH INTO THE UNDERSTANDABILITY OF BUSINESS PROCESS MODELS", Proceedings of the European Conference on Information Systems (ECIS) 2014, Tel Aviv, Israel, June 9-11, 2014, ISBN 978-0-9915567-0-0
http://aisel.aisnet.org/ecis2014/proceedings/track06/7

ON THE THEORETICAL FOUNDATIONS OF RESEARCH INTO THE UNDERSTANDABILITY OF BUSINESS PROCESS MODELS

Complete Research

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Abstract

Against the background of the growing significance of Business Process Management (BPM) for Information Systems (IS) research and practice, especially the field of Business Process Modeling gains more and more importance. Business process models support communication about as well as the coordination of processes and have become a widely adopted tool in practice. As the understandability of business process models plays a crucial role in communication processes, more and more studies on process model understandability have been conducted in IS research. This article aims at investigating underlying theories of research into business process model understandability by means of an in-depth analysis of 126 systematically retrieved research articles on the topic. It shows in how far process model understandability research is multi-theoretically founded. Identified theories differ regarding addressed subject matters, their coverage, their focus as well as the underlying notion of model understanding, which is exemplarily demonstrated and discussed in this article. Moreover, implications of the findings are discussed and an outlook on future business process model understandability research and on the integration potential of theories in this field is given.

Keywords: Process Modeling, Understandability, Comprehension, Theory, Theoretical Foundations.

1 Introduction

The development of theory is one of the most important goals and tasks of every scientific discipline, thus also in Information Systems (IS) research. Theory is supposed to represent true and justified knowledge in a domain (Gregor, 2006). Furthermore, a scientific discipline's progress is strongly influenced by the advancement of its theoretical foundations. Thus, the state of theory development in a field of research can be considered a relevant indicator describing its maturity as the theoretical foundations shape the field of research and, moreover, concentrate reliable knowledge in the domain.

This is, correspondingly, valid for the field of Business Process Modeling research. Business process models provide the basis for different important tasks in the context of Business Process Management (BPM) (van der Aalst, 2013), such as process implementation, execution, controlling or systematic process improvement (Houy et al., 2010). Hence, business process models have become highly relevant for IS research as well as for organizational practice (Fettke, 2009). However, business process models can only fulfil their function and purpose if they possess an appropriate quality. Consequently, there is a whole host of research contributions investigating business process model quality (Krogstie et al., 2006; Recker, 2007). In this context, *model understandability* is considered a major quality criterion. Model understandability is especially important when business process models are used to support communication and to create a collective understanding of business processes and the functionality of IS supporting business processes (Krogstie, 2007). Against this background, research into *model understandability* and its influencing factors has a certain tradition and there are quite a number of contributions focusing on the topic.

Many of these research contributions use existing theory as a foundation for their hypotheses or in order to support and justify the development of innovative artefacts. However, looking at these articles it seems that there is not only one single theory to explain phenomena such as relationships or mechanisms leading to a better understandability. In contrast, several theories seem to serve as a basis. Thus, the field of research is conjectured to have a *multi-theoretical foundation*, which will be investigated in more detail in the following. A plurality of theories in model understandability research would have interesting implications and indeed seems appropriate as understanding a model can be considered a widely subjective and individual process. Research into understanding, explaining and predicting such a complex reality seems to profit from the inclusion of different perspectives (Fettke et al., 2012).

However, so far to our best knowledge no fundamental and systematic investigation of theoretical foundations of research into business process model understandability exists. Without an overview of used theories, particular aspects of the current state of theory development in this field of research remain unclear. Furthermore, it currently remains open which are the predominant theories in the context of model understanding and whether an integration of important theories is possible – and if so – whether this is desirable for IS research.

Against this background, it is the *goal* of this article to systematically investigate underlying theory of research into the understandability of business process models by means of an in-depth analysis of existing research contributions. In this context, we concentrate on the following research questions:

RQ1: (a) *Which particular theories are commonly used as the foundations of business process model understandability research and (b) how are they used?*

RQ2: *Do theories in business process model understandability research address the same subject matters and do they have a similar focus and coverage?*

RQ3: *Do theories in business process model understandability research provide a consistent conceptualization of model understanding and can they be integrated?*

To clarify these research questions, we start with a systematic retrieval and review (Cooper and Hedges, 1994) of research contributions concerning process model understandability research. Moreover, our *research approach* continues with an in-depth analysis and discussion of the findings. However, integrating the found theories into a unified theory of process model understanding is *not* the goal of this article. In contrast, it explicitly aims at preparing future theory integration by investigating the theoretical foundations and the potential for a unified theory.

Our article has the following *structure*: after this introduction, the conceptual background of our research is introduced in section two. Section three clarifies our research approach before section four presents the results of our systematic literature analysis. Section five discusses the findings and presents implications before section six concludes the article.

2 Conceptual Background

2.1 Theory in Information Systems

Science and humanities aim to develop knowledge on the basis of established research methods. However, the term *knowledge* has been controversial for as long as researchers have been thinking about it and there is still no consistent understanding. In this contribution, we understand knowledge in a "classical" sense as a belief or opinion which is justified on the basis of acceptable justification standards and, furthermore, satisfies the claim of being true (Fettke et al., 2010). A common term for a structured representation of scientific knowledge is *theory* (Frank, 2006). This term is not consistently used either and still under discussion. In IS research several contributions describing and explaining the term *theory* exist. One framework aiming at the description of the *Nature of Theory in Information Systems* which has been considered in our research was proposed by Gregor (2006). It provides an overview of characteristics of theory in IS differentiating five theory types which are interrelated:

(I) *Theory for analysing*: the "lowest level" of theory that is concerned with properly defining a theory's constructs without describing relationships between them (*terminology*),

(II) *Theory for explaining*: aims at explaining phenomena by providing a deeper understanding of *how* and *why* a relationship between two or more constructs exists,

(III) *Theory for predicting*: supports the prediction of *what* will be, not necessarily based on a deeper understanding of *why* this happens,

(IV) *Theory for explaining and predicting* (*EP Theory*): supports both the prediction of *what* will happen as well as the explanation for *how* and *why* it will happen and

(V) *Theory for design and action* (so-called *Design Theory*): supporting the design, construction and usage of IS artefacts, sometimes based on established explanation or prediction models.

This framework has been frequently used and referenced in IS research in recent years. However, there are further IS contributions defining the term *theory* by means of different criteria; such as *structural characteristics* or *justification standards* (Frank, 2006). Nevertheless, in our contribution, we do not aim at proposing a new (normative) definition of the term *theory*. In contrast, it is another goal of this article to analyse and describe how the IS community and especially researchers investigating model understandability use the term *theory* in their contributions. Thus, we concentrate on the description how the term *theory* is used instead of arguing for one particular understanding of the term *theory*.

2.2 Business Process Modeling and Process Model Understandability

Business process models are an important instrument to express and clarify the course of activities in the context of value creation in organizations (Curtis et al., 1992). They provide the basis for many different other tasks in BPM and help to communicate and coordinate work as well as information and data flows in companies and administrations. Furthermore, process models are important artefacts for the design of process-oriented IS as they aim at documenting and communicating system functionalities and structures (Scheer, 1999). Against this background, it is critical that business process models have a high quality and be easily understandable for all stakeholders.

The definition of model understandability is not consistent in literature and significantly differs based on various factors like underlying theory, model user perspective or model purpose (Krogstie et al., 2006). This is exactly in line with existing research contributions indicating that *model quality* in general and *model understandability* as one important aspect of model quality are often differently conceptualized and operationalized (Houy et al., 2012; Moody, 2005).

In quite a lot of research contributions an exact definition of *model understandability* is not given but implicitly accessible looking at the used instruments to measure model understandability, which has been investigated in more detail in (Houy et al., 2012). As different theories, methods and measurement instruments have indeed been used in business process model understandability research – which will be shown for theories in the following – it is actually hard to give an all-embracing definition. However, *model understandability* can be regarded as an important quality aspect of conceptual models in general and business process models as well. It is related to the *ease of use* and *effort for reading and correctly interpreting a model*, which is a cognitive process of assigning meaning to the parts of a model (Patig, 2008). Thus, understandability can be interpreted as a kind of *pragmatic quality* of conceptual models (Moody et al., 2003). In recent years model understandability has gained tremendous importance and a whole host of research has been conducted in order to identify underlying principles, characteristics or factors influencing understandability to improve process modeling success. Investigated factors are e. g. model-related factors such as *control flow complexity* (Cardoso, 2008) or secondary notation (Schrepfer et al., 2009), personal factors such as *cognitive style*, *domain knowledge* or *modeling expertise* of a person reading a model (Reijers and Mendling, 2011).

In this context, more or less "established" theories from different fields of research have been used, e. g. from *Cognitive Psychology*, as a fundament – as will be demonstrated in more detail in the remainder of this article. Undoubtedly, one of the most important purposes of using theories in this context is the deduction of hypotheses on process model understandability which can then be tested in the course of empirical or especially in experimental research settings. However, theories can also be used to explain and justify speculative ideas which need further formalization and empirical testing; e. g. during the development of well understandable process modeling languages.

3 Research Approach

In order to analyse the usage of theories and, thus, the theoretical foundations of process model understandability research we have systematically retrieved available research articles on this topic. Systematic retrieval helps to avoid subjective decisions and coincidence and to considerably improve the reproducibility of results (Cooper and Hedges, 1994; vom Brocke et al., 2009).

We have used several search terms in the widely used literature database SCOPUS in order to retrieve relevant journal and conference contributions by means of a forward search addressing articles on process model understandability in general as well as articles on the understandability of common process modeling languages. These terms were *iteratively improved* during the search process based on found articles by means of an inclusion of relevant identified synonyms. We searched for *("process model*" OR "process descri*" OR "process diagram*" OR "business process*" OR bpmn OR epc OR "petri net*" OR "UML Activity" OR "UML collaboration" OR yawl)* in the title in order to find adequate articles on process modeling and restricted the amount of articles by searching for *((understandab* OR comprehens* OR understanding OR comprehending OR "making sense" OR complexity OR cognitive OR perce*) AND "business process")* in the abstract to make sure that the topic of understandability including the common synonyms is treated in the context of business processes. Thus, we have received 121 documents, of which 88 were deemed relevant for our study after manually checking their content.

On this basis, we started a backward search using these articles' reference lists because several relevant articles on the topic which could be found in the reference lists were not covered by the literature database. Thus, we identified further 30 articles in the first round. Based on these newly retrieved 30 articles, we have conducted a further backward search and identified another eight new articles in the second round resulting in a total of 126 articles on process model understandability.

After the literature retrieval we investigated these articles regarding their theoretical foundations. Indeed this is not a trivial undertaking. In order to be able to consistently identify theories, it has to be clear what should be considered a *theory*. We have already mentioned that the term *theory* and its constitutional characteristics are still under discussion, and there are different notions and opinions. As choosing one of the existing *normative* definitions of *theory* would not satisfy the requirements of many other normative theory definitions, we have chosen a *descriptive* approach and have investigated those "theories" which have been regarded as "theories" by the IS community in their articles.

According to this assumption and in line with Lim et al. (2009), we have identified mentioned theories by searching for the truncated search term "theor*" in the full texts in a first step in order to minimize human error. Thus, we have found "theories" and theoretical models which have the phrase "theory" in their name such as the *Cognitive Load Theory*. Furthermore, we have investigated text passages in the underlying articles with corresponding headings such as *theoretical foundations* or *theoretical background*. These passages typically include relevant theories and theoretical models which could be extracted even if they do not contain the phrase "theory" in their name such as *COGEVAL* (Bajaj and Rockwell, 2004) or the *Cognitive Dimensions Framework* (Green and Petre, 1996). Based on that, we have *inductively* and *iteratively* developed a *collection of relevant theories* by first manually scanning these passages. In a further step, we have checked the whole corpus of articles once again for all identified theories by searching for them in the full texts. These steps were first performed by one of the authors. Then the correctness of results was checked and verified by another author in order to improve their validity and to reduce the influence of subjectivity. This whole procedure of developing and checking the theory collection was iteratively performed until "saturation" could be stated and no further theories or theoretical models could be identified. Intermediate results were discussed several times. Occurring discrepancies were clarified and settled through discussion by the authors.

It should be noted that – in line with Lim et al. (2009) – in the whole process only those theories have been picked which were used to deduce hypotheses or which have been used to substantially explain thoughts and ideas in the underlying articles. We have not considered theories which were only mentioned without further argumentation or explanation *why* a theory has been of relevance for model understandability research.

4 Theory Usage in Process Model Understandability Research

4.1 Theories Used in the Samples (RQ1a)

A subset of 80 articles (~63%) explicitly uses theories or theoretical models. The other 46 articles do not use or refer to theories.[1] We have documented identified theories in table 1 in chronological order regarding their publication date. As regards content, we differentiate three major categories of theories used in our sample: (**A**) *core IS/modeling-related theories*, (**B**) *theories on cognition* and (**C**) *other theories*. We have assigned every identified theory to the theory category which best fits its character ("classification"). Although many of the theories in table 1 stem from the field of Cognitive Psychology, quite a number of IS-specific theoretical models in the context have emerged especially in recent years. An IS-specific theory development and scientific progress in this context is, thus, recognizable. However, it has to be confirmed that most identified IS-specific theories are not exclusively related to the topic of process model understandability but to topics like *Complexity Measurement* or *Technology Acceptance*. Nevertheless, there are also some exceptions; e. g. the Guidelines of Modeling (GOM) (Becker et al., 2000) also provide specific guidance for the development of process models and, moreover, recommend design strategies for specific process modeling techniques such as Event-Driven Process Chains (EPCs).

[1] All 126 analysed contributions have been documented and marked with "*"in the references section.

Theory Name	Source	Cl.	Theory Name	Source	Cl.
1. Information Processing Theory	(Miller, 1956)	**B**	18. Technology Acceptance Model	(Davis, 1989)	**A**
2. Role Theory	(Biddle and Thomas, 1966)	**C**	19. Bunge-Wand-Weber Model	(Wand and Weber, 1990)	**A**
3. Psychological Type Theory	(Jung, 1971)	**C**	20. Cognitive Fit Theory	(Vessey, 1991)	**B**
4. Human Information Processing	(Newell and Simon, 1972)	**B**	21. Dual Coding Theory	(Paivio, 1991)	**B**
5. Theory of Expertise	(Chase and Simon, 1973)	**B**	22. Resource Allocation Theory	(Kanfer et al., 1994)	**B**
6. Theory of Working Memory	(Baddeley and Hitch, 1974)	**B**	23. SEQUAL	(Krogstie et al., 2006)	**A**
7. Behavioral Theory	(Fishbein and Ajzen, 1975)	**C**	24. Cognitive Th. of Visual Interaction	(Rogers, 1995)	**B**
8. Theory of Symbols	(Goodman, 1976)	**C**	25. Cognitive Dimensions Framework	(Green and Petre (1996)	**A**
9. Cognitive Restructuring	(Meyer, 1976)	**B**	26. External Cognition Theory	(Scaife and Rogers, 1996)	**B**
10. Feature Integration Theory	(Treisman and Gelade, 1980)	**B**	27. Software Measurement Framework	(Briand et al., 1996)	**A**
11. Spreading Activation Theory	(Anderson, 1983)	**B**	28. Weyuker's properties	(Weyuker, 1998)	**A**
12. Mental Operations Theory	(Gilmore and Green, 1984)	**A**	29. DISTANCE Framework	(Poels and Dedene, 2000)	**A**
13. Model of Experiential Learning	(Kolb, 1984)	**B**	30. Guidelines of Modeling (GOM)	(Becker et al., 2000)	**A**
14. Theory of Action	(Norman, 1986)	**C**	31. Cognitive Th. of Multim. Learning	(Mayer, 2001)	**B**
15. Social Cognitive Theory	(Bandura, 1986)	**B**	32. Communication Flow Optimization Th.	(Kock, 2003)	**A**
16. Informational Equivalence	(Larkin and Simon, 1987)	**B**	33. COGEVAL	(Bajaj and Rockwell, 2004)	**A**
17. Cognitive Load Theory	(Sweller, 1988)	**B**	34. Physics of Notations	(Moody, 2009)	**A**
Legend: (**Cl.**) *classification*, (**A**) *core IS/modeling-related theory*, (**B**) *theory on cognition* and (**C**) *other theory*					

Table 1. Identified theories used in process model understandability research

Table 3 on the next page comprehensively documents the usage of theories in more detail. Articles are arranged in chronological order top down, which illustrates how the usage of theories has developed over the years. Theories are arranged related to the number of occurrences from left to right.

In general, it shows that in recent years not only more and more contributions on the topic have been published but also that using appropriate theoretical foundations seems to have gained further relevance in process model understandability research. The number of references to theories tendencially increases over the years, which is illustrated in table 2. This observation fits the "generally expected development" in IS research towards a stronger and more distinctive theoretical foundation which is supposed to lead to a further development of dedicated IS theories (Weber, 2003).

Development of theory usage	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Sum
Number of articles citing theories	1	0	0	3	0	1	2	2	1	5	1	5	8	11	12	13	11	4	**80**
Number of theory citations	2	0	0	11	0	2	3	4	2	6	1	13	15	31	44	42	40	22	**238**
Number of different cited theories	2	0	0	8	0	2	3	2	2	6	1	9	10	22	17	15	17	10	-

Table 2. Development of theory usage

Based on the number of citations of each theory, table 3 on the next page also illustrates that the long tail phenomenon described by Lim et al. (2009) in the context of theory usage in IS research in general can also be identified in process model understandability research. Although it could be expected that especially older and "more established" theories occur more often when investigating the theory references – which could lead to a potential bias – it becomes obvious that also several more recent theories like the *Physics of Notations* or *SEQUAL* are among the most cited theories.

Usage of theories in process model understandability research

Legend:

● theory has been used in assigned article

Usage of theories in process model understandability research	1. Cognit. Dimen. Framework	2. Informational Equivalence	3. Cognitive Load Theory	4. Cognit. Th. of Multim. Learn.	5. Cognit. Fit Theory	6. Information Processing Theory	7. Physics of Notations	8. SEQUAL	9. Dual Coding Theory	10. Softw. Measurem. Framew.	11. External Cognition Theory	12. DISTANCE Framework	13. Guidelines of Mod. (GOM)	14. COGEVAL	15. Feature Integration Theory	16. Theory of Action	17. Weyuker's properties	18. Bunge-Wand-Weber Model	19. Human Inform. Processing	20. Techn. Acceptance Model	21. Theory of Working Memory	22. Behavioral Theory	23. Communic. Flow Optimiz.	24. Mental Operations Theory	25. Theory of Symbols	26. Cognit. Th. of Vis. Interact.	27. Cognitive Restructuring	28. Model of Experient. Learn.	29. Psychological Type Theory	30. Resource Allocation Theory	31. Role Theory	32. Social Cognitive Theory	33. Spreading Activation Theory	34. Theory of Expertise	**Number of used theories**
1. (Agarwal et al., 1996)					●														●																**2**
2. (Agarwal et al., 1999)		●			●														●																**3**
3. (Britton and Jones, 1999)	●	●									●				●																				**4**
4. (Hahn and Kim, 1999)	●	●																			●					●									**4**
5. (Lainema, 2001)																●												●							**2**
6. (Genero et al., 2002)												●																							**1**
7. (Moody et al., 2002)								●												●															**2**
8. (Genero et al., 2003)										●		●																							**2**
9. (Miranda et al., 2003)										●		●																							**2**
10. (Cruz-Lemus et al., 2004)										●		●																							**2**
11. (Caetano et al., 2005)																															●				**1**
12. (Cardoso, 2005)																	●																		**1**
13. (Cruz-Lemus et al., 2005b)										●		●																							**2**
14. (Danesh and Kock, 2005)																							●												**1**
15. (Glezer et al., 2005)														●																					**1**
16. (Cardoso et al., 2006)						●																													**1**
17. (Aranda et al., 2007)	●	●		●	●					●	●																								**6**
18. (Cruz-Lemus et al., 2007)				●																															**1**
19. (Mendling et al., 2007)								●					●																						**2**
20. (Recker and Dreiling, 2007)		●		●	●																														**3**
21. (zur Muehlen et al., 2007)																		●																	**1**
22. (Cardoso, 2008)						●											●																		**2**
23. (Cruz-Lemus et al., 2008)				●						●		●																							**3**
24. (Genero et al., 2008)				●																															**1**
25. (Mendling and Recker, 2008)				●					●																										**2**
26. (Mendling and Strembeck, 2008)	●							●					●																						**3**
27. (Patig, 2008)		●																																	**1**
28. (Rolón et al., 2008)										●																									**1**
29. (Vanderfeesten et al., 2008a)	●							●																											**2**
30. (Cruz-Lemus et al., 2009)				●					●																										**2**
31. (Fahland et al., 2009)	●																							●			●								**3**
32. (Figl et al., 2009)	●	●	●	●	●	●			●		●			●		●		●			●												●		**13**
33. (Gruhn and Laue, 2009)			●																																**1**
34. (Han and Zhang, 2009)																	●																		**1**
35. (Heravizadeh et al., 2009)																●																			**1**
36. (Kock et al., 2009)																							●												**1**
37. (Melcher et al., 2009)	●																																		**1**
38. (Moody and Hillegersberg, 2009)		●				●	●								●										●										**5**
39. (Rolón et al., 2009)										●																									**1**
40. (Schrepfer et al., 2009)	●																																	●	**2**
41. (Cruz-Lemus et al., 2010)										●		●																							**2**
42. (Figl et al., 2010b)		●	●	●	●	●			●		●			●							●														**9**
43. (Figl et al., 2010a)	●	●	●	●	●	●	●		●					●																					**9**
44. (González et al., 2010)										●																									**1**
45. (Holschke, 2010)		●					●																												**2**
46. (Melcher et al., 2010)	●																																		**1**
47. (Mendling et al., 2010b)				●					●																										**2**
48. (Mendling et al., 2010a)	●			●				●	●				●																						**5**
49. (Mendling et al., 2010c)	●							●					●																						**3**
50. (Reijers et al., 2010)				●			●															●													**3**
51. (Rittgen, 2010)					●			●												●		●													**4**
52. (Sánchez-González et al., 2010a)	●							●					●																						**3**
53. (Cortes-Cornax et al., 2011)							●	●	●																										**3**
54. (Dhillon and Dasgupta, 2011)																													●			●			**2**
55. (Figl and Laue, 2011)			●																																**1**
56. (Genon et al., 2011)	●	●			●	●	●	●	●																●										**8**
57. (La Rosa et al., 2011)	●						●	●										●		●															**5**
58. (Recker and Dreiling, 2011)			●	●	●	●	●																												**5**
59. (Reijers et al., 2011b)	●				●																														**2**
60. (Reijers and Mendling, 2011)	●				●		●																												**3**
61. (Reijers et al., 2011a)	●	●					●																												**3**
62. (Schalles et al., 2011)			●																																**1**
63. (Zugal et al., 2011a)		●	●			●					●																								**4**
64. (Zugal et al., 2011b)	●		●								●																								**3**
65. (Zugal et al., 2011c)	●					●																													**2**
66. (Bera, 2012)		●	●	●	●																														**4**
67. (Claes et al., 2012)			●			●																													**2**
68. (Dumas et al., 2012)	●																																		**1**
69. (Mendling et al., 2012b)			●			●		●								●														●					**5**
70. (Mendling et al., 2012a)	●		●		●								●																						**4**
71. (Ottensooser et al., 2012)	●	●	●	●	●		●		●																										**7**
72. (Pichler et al., 2012)	●							●																●											**3**
73. (Sánchez-González et al., 2012)						●				●							●																		**3**
74. (Soffer et al., 2012)			●	●	●			●											●																**5**
75. (Zugal et al., 2012a)		●	●			●																													**3**
76. (Zugal et al., 2012b)		●	●								●																								**3**
77. (Figl et al., 2013a)	●	●	●	●	●		●		●		●				●																				**9**
78. (Figl et al., 2013b)	●	●	●	●	●	●	●								●																				**8**
79. (Weitlaner et al., 2013)							●		●																										**2**
80. (Zugal et al., 2013)		●	●								●																								**3**
Number of theory usages	**27**	**21**	**20**	**19**	**18**	**15**	**14**	**14**	**12**	**11**	**9**	**7**	**6**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**238**

Table 3. Usage of theories in process model understandability research

An investigation and description of the different types of identified theories according to the Gregor framework was a further step in the context of our analysis. However, in this context, we have faced an interesting aspect of using this meta-theoretical framework for our descriptive empirical analysis. It is known from literature that IS theories can actually serve several purposes, e. g. design theories can also support the explanation of certain technical mechanisms; e. g. *Exploratory Design Theories* according to (Baskerville and Pries-Heje, 2010). Against this background and regarding the fact that theories *can be* and *are* in fact quite differently used in research into process model understandability, in our case it has been almost impossible to strictly categorize each identified theory according to Gregor's framework. However, as a result from this analysis it can be stated that theories fitting all the major theory types in Gregor's framework could be identified in the sample:

a) *Weyuker's properties* are one example for a Type I theory giving definitions for structural properties in the context of the evaluation of software complexity measures. A further example is the *Bunge-Wand-Weber Model* which represents a framework for the analysis and conceptualization of real world objects without considering cause-effect relationships.

b) Depending on the context, most common theories on cognition strive for either the explanation (Type II) or prediction (Type III) of relationships between defined theoretical constructs – or even both at a time (Type IV) – such as the *Cognitive Load Theory* (Sweller, 1988), the *Dual Coding Theory* (Paivio, 1991) or the *Cognitive Fit Theory* (Vessey, 1991).

c) Many of the identified theories are supposed to specifically support the design of modeling languages or acting with existing modeling languages, such as the *Cognitive Dimensions Framework* by Green and Petre (1996) or the *Physics of Notations* by Moody (2009). These examples can be considered typical Type V theories according to Gregor.

In the following section, we investigate how the most cited theories in the sample are actually used.

4.2 How the Most Cited Theories are Used in the Sample (RQ1b)

In the following, the usage of the five most important theories in the set of 34 theories cited in process model understandability research will be investigated in more detail.

1. *Cognitive Dimensions Framework (CDF)* (Green and Petre, 1996): This framework comprises design principles and guidelines for well-usable notations or models based on 14 cognitive dimensions which should be clarified during the design process, e. g. *consistency*, *closeness of mapping* or *hidden dependencies*. In our sample, these guidelines are used, e. g. as a basis for the definition of structural metrics for process model understandability in (Sánchez-González et al., 2010a) or to justify an adaption of a modeling notation for more understandable models, e. g. by using colour highlighting in (Reijers et al., 2011a). Moreover, it is sometimes argued that visually *hidden dependencies* between parts of modular models should be avoided in order to have models which are easier to understand.

2. *Informational Equivalence* (Larkin and Simon, 1987): Informational equivalence of two models expresses the fact that all information in the one model can be inferred from the other and vice versa if they are informationally equivalent. In the investigated sample, this principle is mostly used to justify a particular experimental research design, e. g. in (Figl et al., 2013b; Ottensooser et al., 2012; Patig, 2008) or to develop dedicated hypotheses to be tested later on (Recker and Dreiling, 2007).

3. *Cognitive Load Theory (CLT)* (Sweller, 1988): *CLT* describes influences of working memory load on learning and knowledge acquisition while differentiating intrinsic cognitive load (CL - determined by inherent characteristics of the information such as the number of elements or complexity), extraneous CL (determined by the presentation of information) and germane CL (related to the effort of learning and understanding information). In our sample, the CLT is often used to hypothesize on and also to explain *why* certain model characteristics, e. g. a reduced number of elements, avoiding "crossing lines", reduced number of gateways or the application of certain design patterns in a process

model leading to a lower extraneous CL result in more understandable process models, e. g. in (Gruhn and Laue, 2009). Furthermore, the CLT is sometimes used to develop appropriate criteria for the comparison of different modeling notations regarding their general understandability and the related learning performance, e. g. in (Figl et al., 2009).

4. *Cognitive Theory of Multimedia Learning (CTML)* (Mayer, 2001): *CTML* assumes that the capacity of the two information reception channels (*auditory* and *visual*) is limited and that information should be filtered, selected, organized and integrated to achieve an optimal reception of new information. In our sample, the CTML is mostly used to differentiate and measure two levels and degrees of understanding a process model: surface-level understanding (*retention*) and problem-solving (*transfer*). In several contributions it has been argued that – besides the visual reception of graphical elements in a model – peoples' auditory channel is addressed via reading the words in labels of a process model "in their minds"; e. g. in (Mendling and Recker, 2008). Thus, most process modeling notations address both channels.

5. *Cognitive Fit Theory (CFT)* (Vessey, 1991): *CFT* formulates a broadly supported positive relationship between an adequate and well-fitting presentation of information regarding a certain task which has to be fulfilled on the one side and a superior individual task performance and problem-solving performance on the other side. In our investigated sample, the CFT has been used to explain and hypothesize on the differences in understanding and especially in problem-solving performance when using various types of conceptual modeling techniques for certain tasks, e. g. in (Agarwal et al., 1999), or when comparing different business process modeling notations such as in (Figl et al., 2009). Furthermore, it has been used to explain and hypothesize on differences when comparing the problem-solving performance of different people; e. g. (Ottensooser et al., 2012) conjectures a positive relationship between problem-solving performance on the one side and a good cognitive fit of a process modeling notation and the cognitive style of a person on the other side.

To draw a *general conclusion* from our analysis, it can be stated that besides other, less relevant purposes of theories in our sample we found especially four major purposes for the usage of theories:

(I) as a basis for the conceptualization and operationalization of understanding a model diagram especially in experimental settings,

(II) for the deduction of hypotheses,

(III) for the development of criteria for model quality measurement and

(IV) for justifying proposed model design characteristics.

4.3 Subject Matters, Focus and Coverage of Used Theories (RQ2)

In this section, a comparison of characteristics of used theories regarding their addressed IS *subject matters* as well as their *focus* and *coverage* is undertaken in order to contribute to the clarification of RQ2. We have deduced this set of chracteristics from works defining the term *theory*, e. g. from the definitions given in (Gregor, 2006) and (Frank, 2006). These characteristics provide useful categories for a more detailed description of theory usage and for the comparison of different theoretical lenses. Also in this context, we have to concentrate on major aspects to be found in the literature sample and exemplarily illustrate them due to limited space.

Subjects Matters. Identified theories can support and are actually used for research into quite different subject matters in the context of model understandability. However, typically each theory addresses one or a few particular subject matters – their particular purpose which has a significant influence on the underlying notion of model understanding. The major subject matters addressed by contributions in the sample are the following three:

(I) *the design of easily understandable models to support efficient and effective information systems design (e. g. supported by Cognitive Dimensions Framework, Physics of Notations or the Guidelines of Modeling),*

(II) *the investigation and improvement of general model quality and complexity (e. g. supported by SEQUAL, the DISTANCE Framework or COGEVAL) and*

(III) *the study of cognitive factors influencing model understanding in order to improve autonomous learning and teaching of business process modeling approaches (e. g. supported by Cognitive Theory of Multimedia Learning, Cognitive Load Theory, Cognitive Fit Theory, or the Dual Coding Theory).*

Surely, there are also further subject matters which identified theories can notably support. However, the above mentioned subject matters are the major ones which we found in our sample and which can be considered “core areas” of business process model understandability research. In the context of these core areas, certain “clusters” of dedicated theories offering specific explanations, predictions or design proposals are available and used in the analysed contributions.

Focus and Coverage. To generally illustrate the diversity of used theories in research into process model understandability, we exemplarily take a look at the *focus and coverage* of several theories on cognition. In this context, at least three different focus levels can be differentiated:

(I) *theories completely focussing on internal cognition such as the Cognitive Load Theory, the Dual Coding Theory or the Theory of Working Memory,*

(II) *theories looking at the external influences such as characteristics of texts, models or auditory influences on cognition (“external cognition”), e. g. the External Cognition Theory, Cognitive Fit Theory or the Feature Integration Theory or*

(III) *theories concentrating on group cognition phenomena, e. g. the Social Cognitive Theory.*

Such differences of focus and coverage of theories can also be observed regarding design theories which sometimes address the design of modeling languages or notations (*Physics of Notations*), or the design of the models (*Guidelines of Modeling*).

4.4 Conceptualization of Understanding and Integrability of Theories (RQ3)

In this section the *potential for integrating theories* is analyzed based on the different theories’ conceptualization of understanding. Looking especially at the conceptualization of understanding of theories on cognition, considerable differences can be identified. Several theories on cognition aim at explaining and predicting reliable relationships between diverse independent variables concerning model characteristics (*language used*, *decomposition* etc.) or characteristics of persons dealing with a model (*education*, *domain knowledge* etc.) and the dependent variable *model understanding*. However, the dependent variable *model understanding* is quite differently conceptualized by different theories. This observation is in line with the results in (Houy et al., 2012) and (Houy et al., 2013) which investigate the methodical perspective of model understandability research. While, e. g. the main dependent factors of *Cognitive Fit Theory* (*Problem Solution*, *Problem Solving Performance* and *Task Performance*) and *Cognitive Load Theory* (*Performance* related to knowledge acquisition, learning, problem-solving) could be convincingly mapped onto each other to a large extent, it is questionable *whether* and *how* exactly this could be done, e. g. with the conceptualization of understanding of other related theories like Miller’s *Information Processing Theory* which is composed of the factors *perception*, *thinking*, *learning*, *memory*, *attention*, *creativity* and *reasoning*. Thus, the comparability of results from studies with different underlying theories is questionable.

However, more recent theories are more and more connected to prior theories or contain elements of prior theories; e. g. the *Cognitive Theory of Multimedia Learning* directly refers and picks up central elements of the *Cognitive Load Theory* and the *Dual Coding Theory*. Furthermore, recent design theories, e. g. the *Physics of Notations*, also refer to well-known theories on cognition, such as the *Dual Coding Theory* or the *Cognitive Fit Theory*. Thus, newer theories tend to take over general ideas and also detailed conceptualization of prior theories. Against this background, it can be stated that first attempts of integrating particular ideas of existing theories into newer theories indeed exist. However, there is a lot more potential for an integration of existing theories in process model understandability research and further research is necessary, which will also be discussed in the following section.

5 Discussion

Our review showed that only a subset of 80 articles (~63%) uses or substantially refers to theories. More than 36% of the literature sample does not refer to existing theories or theoretical models but rather aims at exploring the field of research. Analogous to the discussion in (Hacking, 1983, pp. 201ff.), such contributions typically come up with starting points for theory building by means of speculative ideas, the formalization of these ideas or they develop technical solutions without referring to specific theories. Nevertheless, it can also be stated that the theoretical foundations of the growing field of research into model understandability have gained more and more relevance in recent years, which is indicated by a growing number of theory citations. This fact could to a certain extent also be related to a common IS publication guideline towards a stronger usage and citation of theories which has gained attention and is being followed more often in recent years.

However, in any case it has clearly shown that the field of process model understandability research is not dominated by one particular theory. In contrast, a multitude of theories is used to provide the basis for research into the topic and we could identify a *long tail* of theory usage. Besides the usage of explanatory and predictive theories on model understandability from the field of Psychology, it became obvious that also several theories from the field of IS and Conceptual Modeling as well as some IS design theories for process models have been developed and used as theoretical foundations for research articles in our sample. This signalizes progress in the on-going course of the development of dedicated IS theories and helps to strengthen and justify our community's work. It was, furthermore, found that especially the most recent theories developed in the IS/Modeling context build upon the "well-established" and empirically well-founded knowledge on human understanding processes from the field of Cognitive Psychology. Thus, well-founded but also specific IS theories are currently developed which concentrate on *how* humans understand conceptual models.

As shown in section 4.3, investigated theories treat different subject matters in the context; they have different focuses as well as a different coverage of the topic resulting in different theoretical lenses on the topic of process model understandability. We have presented the most important characteristics and categories found in our analysis which sometimes strongly differ. Thus, identified theories are only to a certain extent integrable, mostly due to different conceptualizations of model understanding. However, research into process model understandability comprises different core areas and, thus, requires different views and perspectives on process model understandability. Hence, against the background of a growing amount of available specific theories and theoretical frameworks, each study chooses fitting theoretical foundations for their particular argumentation, experimental set up or design propositions according to the identified core areas and major subject matters.

Based on that, a more and more differentiated view on the topic of process model understandability evolves. Against this background, it is quite common that during their historical development scientific disciplines run through phases of theory consolidation carving out an "established" theory base and, thus, developing from *pre-paradigmatic* to a so-called *normal sciences* with "settled" paradigms (Kuhn, 1996). This, as well as the fact that several of the used theories refer to each other or are substantially connected to each other, suggest that there is potential for a partial integration and consolidation of theories in the future. Several attempts of unifying theories are known in the context of IS research; e. g. regarding *Technology Acceptance* (Davis, 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003). However, in the context of process model understandability, theories' addressed subject matters, focus and coverage as well as their underlying conceptualization of model understanding so far seem to be too diverse for one *unified theory of process model understanding*. Nevertheless, theory integration seems to be possible to a certain degree, especially regarding comparable theories related to the same or similar core areas and major subject matters.

Our study revealed that a variety of different theoretical models is used for very different purposes. Although an integrated and unified theory of model understanding seems desirable at first sight, it remains open whether a unified theory could provide the same benefits as the usage of the different individual and at the same time more specialised theories. During the integration and unification of theories, certain abstraction processes are essential in order to be able to map different constructs. However, abstraction and mapping processes are typically accompanied by a loss of specificity and thus, by a loss of specific details. Further investigation and research into this problem regarding the special characteristics of theories used in model understandability research is needed.

Besides the general question *whether* an integrated and unified theory of process model understanding is desirable, it can, however, be argued that further research into the consistency and potential contradictions of different theories is necessary; e. g. how to deal with potentially contradictory propositions provided by the *Physics of Notations* such as (I). the need for clearly distinguishable, semiotically clear and visual expressive elements of a modeling language (*Principles 1*, *2*, *6*) on the one side and a cognitively manageable number of elements on the other side (*Principle 8*). In BPM practice, this area of conflict is also known regarding the *Business Process Model and Notation* (BPMN) which offers a lot of different graphical constructs ("over-engineering") of which only a limited choice is actually used in practice (Recker, 2010). Moreover, the mentioned difference in the conceptualization of model understanding in the identified theories could complicate their integration.

Regarding theory integration Stark and Esswein (2012) aimed at building up an integrated view of human cognition and conceptual modeling. In this work, a model of "rules from cognition for conceptual modelling" is proposed based on the integration of used constructs in the hypotheses of 13 empirical contributions considering data, object and process modeling. The focus of this work is more on data and object models and schemata. Central hypotheses from the underlying works were gathered and integrated into a framework with several *tested* but also some *merely conjectured* relationships. The central dependent variable is *model understanding*. This model offers interesting insights for model understandability research and has, in contrast to our more theoretical perspective, an empirical focus. However, against the background of studies confirming differences between the process of understanding data and object models on the one side and the process of understanding process models on the other side, e. g. (Agarwal et al., 1999), it has to be further investigated whether these differences can be confirmed in further studies. If so, it would be necessary to strictly separate studies looking at data and object schemata from studies looking at process schemata when trying to develop theories of model understanding. Against this background, our work concentrates on process model understandability and, so far, we have taken a pure theoretical perspective on the topic.

Our contribution has some *limitations* which shall be mentioned here. First of all, we have investigated a comprehensive sample of systematically retrieved literature sources. Although we have carefully chosen and described our research approach in order to support a valid and objective analysis with a high reproducibility of results, it cannot be completely excluded that we have not considered every existing contribution on process model understandability. However, we have tried to assure valid and objective research results by means of careful forward and backward searches and a controlled and iterative process of developing our theory collection. Moreover, as already mentioned different notions of the term *theory* exist; thus, we have considered those objects as "theories" which have been regarded as "theories" by the IS community in the underlying articles. This leads to a rather broad and consensual understanding of *theory*. Thus, we present a strongly descriptive view on theory usage based on the community's understanding of the term *theory*. It could be argued that particular notions of the term *theory* are not satisfied by every theory in the presented theory collection. However, we believe that this effect is not as serious as the expected effect when choosing one particular normative definition of the term *theory*. Although it would have been interesting to investigate the usage and specialities of every single theory or certain theory clusters in more detail, the amount and diversity of used theories has not allowed for more detailed descriptions in this article. However, the presented research describes substantial tendencies and developments in the context of current research into process model understandability and concentrates on giving answers to the research questions formulated in section one.

6 Conclusion

Against the background that theories represent important corner stones of scientific progress and help to define the core areas of scientific disciplines, the presented article has investigated the theoretical foundations and the actual use of theories in business process model understandability research as a growing field in the context of Information Systems and BPM. Our analysis revealed that theoretical foundations gain more and more importance in research into process model understandability. Moreover, we identified quite an amount of different but often quite closely related theories mostly stemming from the field of Cognitive Psychology. It showed and it was argued that based on their characteristics, identified theories could be further integrated within each of the found core areas of research on process model understandability: (I) *the design of easily understandable models to support efficient and effective IS design*, (II) *the investigation and improvement of model quality and complexity* and (III) *the study of cognitive factors influencing model understanding to improve autonomous learning and teaching of business process modeling*.

The *main contributions* of our article are the following: (I) The analysis reports on trends in theory usage in process model understandability research. (II) The given overview can support process model understandability researchers in finding adequate theoretical foundations for their own arguments, hypotheses for experimental work or even in finding valuable but seldom used theories offering new insights and further research opportunities (Lim et al., 2009). (III) The collection of relevant theories and the consideration of contained relationships can support the development of a better understanding of influencing factors on process model understandability named and defined in these theories. Such knowledge is important for process modeling practice as it can facilitate modeling processes which are easier to understand for the different stakeholders.

Our *research agenda* for the future is as follows: (I). We plan to compile available empirical research results in order to identify reliable empirical patterns as well as contradictory empirical results. (II). We plan to compare these results with the available related theories regarding the following questions "*Which theories are able to reproduce the empirical results*?", "*Which theories have better explanations for certain empirical phenomena*?" and "*Which empirically observable phenomena have so far not been addressed by known theories for process model understanding*?". (III). Based on the findings, we plan to refine existing theoretical models and maybe also to develop new theoretical approaches or models based on the available empirical results. Considering the results in (Houy et al., 2012) and this analysis it becomes apparent that future research on process model understandability should further refine and improve the methodical and theoretical basis to improve the provided empirical results for the benefits of process modeling research and especially for modeling practice.

Acknowledgement: This research was supported by a grant from the German Research Foundation (DFG), project name: *Pluralistische Beurteilung der Qualität von Unternehmensmodellen – Qualitätsdiskurse und Diskursqualität innerhalb der Wirtschaftsinformatik (PluralistiQue)*, support code LO 752/4-1. The authors would also like to thank the three anonymous reviewers, the associate editor and the track chairs for their valuable comments which helped to improve this paper.

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