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Cognitive style and business process model understanding

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Cognitive Style and Business Process Model Understanding

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Abstract. Several factors influence the level of business process model understanding. In this paper, we investigate two personal factors that potentially relate to this level: a reader's cognitive style and theoretical knowledge on business process (BP) modeling. An experiment with 183 graduate students was conducted to explore their differences in cognitive styles using Cognitive Style Index (CSI) and how these relate to their scores in process model understandability. We used two real-life BPMN collaboration diagrams as our process models in our experiment. The results indicate a significant difference between intuitive and analytic students with respect to the level of BP model understandability. The relation between students' theoretical BP modeling and notation competency, and their level of model understanding is also found significant.

Keywords: business process modeling, process model comprehension, model understandability, cognitive style, cognitive style index (CSI), theoretical business process modeling knowledge

1 Introduction

Business process models are widely used as a means to communicate about the course of actions in a business process among various stakeholders (e.g. process owners, process participants, managers, auditors). They facilitate business process analysis and redesign. Often their construction is a manual effort, e.g. a team of humans map the process, read and interpret the process model, and analyze the process's bottlenecks. Because human interpretation is error-prone, cognitive aspects are important in the manual development of business process models.

Over the past decade many researchers have focused on various challenges that the stakeholders face when conducting business process analysis and (re)design. The structural model characteristics that influence the occurrence of modeling errors and of process model comprehension are extensively researched, e.g. [1–3]. More recently, research efforts have focused on investigating how process modelers create a process model [4, 5], on improving notations and visualizations of process models for better understandability [6–9], on identifying the cognitive biases that may lead to issues in the business process management lifecycle [10], and on personal factors of the modelers and model readers that may affect the comprehension of business process models [11, 12].

In this paper, we aim to contribute to the domain of cognitive aspects in business process management by exploring the relation of two personal factors, i.e. the model reader's cognitive style and level of theoretical knowledge on business process (BP) modeling, with process model understanding. This is done empirically with the data from an experiment performed with 183 graduate students. The results show a significant relation of cognitive style and theoretical BP modeling knowledge with process model understanding.

This paper is structured as follows: In Section 2 the background on research into process model understandability and cognitive styles is discussed. Section 3 presents the research design including the hypotheses that were tested, and the set-up of the experiment. Finally, results are discussed in Section 4, and the paper ends with concluding remarks and outlook in Section 5.

2 Background

This section summarizes relevant works on the cognitive aspects of business process modeling and outlines the theory on cognitive styles used for the experiment.

2.1 Related work

To correctly convey the information that is captured in a BP model to the model reader, the understandability of the model is an important factor researched by many studies, e.g. [1, 3, 13]. Most of these works focus on the structural characteristics of the process model, such as the size, density, and complexity, that influence the readability, syntactic and semantic quality, and the understandability of the model. The main motivation behind this is based on the *cognitive load theory* [14], which states that the more complex a model is, the higher the mental load is to comprehend it. When the mental load is too high, the working memory is overloaded and people tend to make more mistakes [20]. Apart from structural characteristics of the process, literature also suggests a number of personal factors that may influence model understandability such as expertise [1, 12] or cognitive abilities and learning style [11].

From the perspective of creating BP models, some works focus on investigating the way a process modeler creates a process model and link the implemented modeling approach to the syntactic and semantic quality and the understandability of the resulting model (e.g., [4], [15]). One of the main conclusions from these works is that modelers have various styles of modeling and that a structured approach (i.e. chunking the big task of creating the process model into smaller pieces) is a better strategy leading to better process models [16]. It is also concluded that modelers with different profiles may use different modeling strategies to be successful [17]. The authors in [18] present an experiment performed with the objective to understand the factors influencing model readers' preference for the process model representation forms (unstructured, semi-formal or diagrammatic). The results indicate that the preferences for the representation forms vary dependent on application purpose and *cognitive styles* of the participants.

2.2 Cognitive styles

In the domain of cognitive psychology, the term cognitive style is used to describe the way individual thinks, perceives and remembers information [19]. The Cognitive Style Index (CSI) is one of the ways to measure cognitive style [19]. It is a psychometric measure designed to be used primarily with managerial and professional groups, but has also been applied successfully with students and non-managerial employees [20]. Despite criticisms, CSI is one of the most widely used measures of cognitive style in academic research in the fields of management and education [21–24]. Its construct validity has been indicated in most previous studies through significant correlations with, for example, various personality dimensions and job level [19, 20], and with scores on the Myers–Briggs Type Indicator [25].

As discussed in [20], CSI builds on Ornstein's left-brain/right-brain theory. Ornstein [26] differentiates between analytic and holistic thinking. The former implies processing information in an ordered, linear sequence, whereas the later involves viewing the whole situation at once in order to facilitate the synthesis of all available information. CSI labels these modes of cognition as 'analytic' and 'intuitive' respectively. Fig. 1 depicts the intuition-analysis dimension assessed by the CSI. Pure cases of 'intuition' and 'analysis' are located at the two sides. The full exercise of either precludes the adoption of the other. The cognitive style of most people, however, involves elements of both cognitive modes. In the middle range, the 'adaptive' implies a balanced blend of the two modes. Either side of this are the 'quasi-intuitive' and 'quasi-analytical' styles, each of which denotes a tendency towards, but not the full adoption of, one of the extreme cognitive modes. Intuitives are characterized as active, cautious, and impulsive; while analytics as passive, risk taking, and reflective [20].

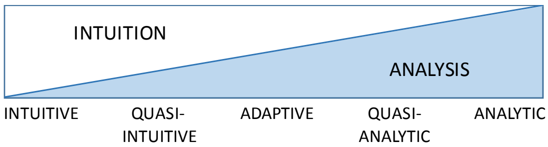


Fig. 1. Continuum of Cognitive Style [20].

Several researchers have investigated the relationship between CSI and various traits and areas of organizational life, such as job level, occupation, culture, entrepreneurship, personality, etc. Literature suggests that occupations that are likely to favour relatively unconstrained thinking (e.g., creative artists, entrepreneurs) tend to score towards the intuitive end of the CSI scale, whereas those likely to adopt a more structured, systematic approach (e.g., engineers, accountants) tend towards the analytical pole [20]. Similarly, the studies by Brigham et al. [27] and Allinson et al. [28] found that the owner-managers of high growth firms were significantly more intuitive than managers in the general population. This is consistent with the idea that intuition is a necessary quality for those operating in an environment characterised by incomplete information, time pressure, ambiguity and uncertainty. Literature has also studied the relation between CSI and academic performance, and suggests that analytic thinkers are likely to score more highly than their intuitive colleagues - regardless of the subject taught [29], [30].

3 Research design

Aligned with our research objective, we identified two *independent* variables for the research design: *cognitive style* and *theoretical BP modeling competency*, which are hypothesized to relate to the *understandability task effectiveness*, as a dependent variable representing the level of BP model understanding. Fig. 2 presents the research model that we propose. The model suggests that the understanding of a business process model is influenced by its reader's cognitive style and level of theoretical BP modeling competency. Accordingly, we can draw the following hypotheses:

- *H1*. The understandability of a business process model is influenced by model reader's cognitive style.
- *H2*. The understandability of a business process model is positively correlated with the model reader's level of theoretical BP modeling competency.

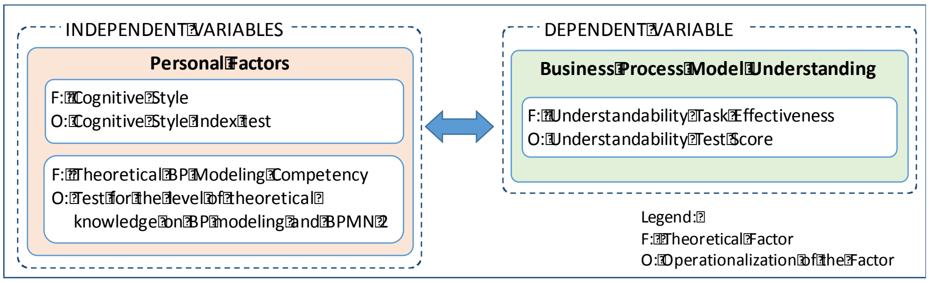


Fig. 2. Research model.

To test these hypotheses, we performed an experiment with the participation of 183 graduate students of the Eindhoven University of Technology, The Netherlands. The experiment was conducted through an extensive questionnaire in 4 main parts. In the first part, the participants went through the CSI test to categorize their cognitive style. The second part was the BP Modeling Competency Test, to assess participants' level of theoretical knowledge on process modeling and BPMN 2.0. As discussed in Section 3.2, the test is developed based on the questions in [12]. The last two parts of the questionnaire were designed to measure participants' level of model understanding for *two different process models*. In these parts, the participants were expected to answer 9 understandability questions related to each of these models.

The experiment took place in January 2017 in a single-session and single-location setting. The questionnaire for the experiment was provided through an online web environment. The process models were embedded in the questionnaire environment in such a way that the question and model were presented on the same page (with zoom-in/-out functionalities for the process model). In the subsections that follow, we explain in more detail the design of the experiment, measured variables and their operationalization, as well as the participants of the experiment.

3.1 Cognitive Style Index

We used the Cognitive Style Index (CSI) of Allinson and Hayes [19] as an instrument to measure the intuitive-analytic dimension of cognitive style. The CSI [20] is a 38-

item self-report questionnaire. Each item has ‘true’, ‘uncertain’ and ‘false’ response options, and scores of 2, 1 or 0 are assigned to each response with the direction of scoring depending on the polarity of the item [20]. The nearer the total score to the theoretical maximum of 76, the more ‘analytical’ the respondent, and the nearer to the theoretical minimum of zero, the more ‘intuitive’ the respondent” (see Table 1).

Table 1. CSI score ranges for the five cognitive styles [20].

Style	Score range
Intuitive	0 – 28
Quasi-Intuitive	29 – 38
Adaptive	39 – 45
Quasi-Analytic	46 – 52
Analytic	53 – 76

3.2 Business Process Modeling Competency (BPMC) Test

To investigate participants’ level of theoretical knowledge on business process modeling and notation, we constructed the Business Process Modeling Competency Test. Taking the questions used in [12] as the basis and extending them, we developed 15 questions related to common process modeling practices (e.g., how basic gateways work, how loops can be defined, etc.) and to the basic constructs of BPMN 2.0. Participants were expected to answer each question by selecting one of the three options: ‘yes’, ‘no’, or ’I don’t know’. Their competency was measured as the total of correctly answered questions and categorized into 6 groups with the following scheme: level 0 with 0 or 1 correct answers, level 1: 2 to 4, level 2: 5 to 7, level 3: 8 to 10, level 4: 11 to 13, and finally level 5 with 14 to 15 correct answers. Fig. 3 shows two examples of questions from the test.

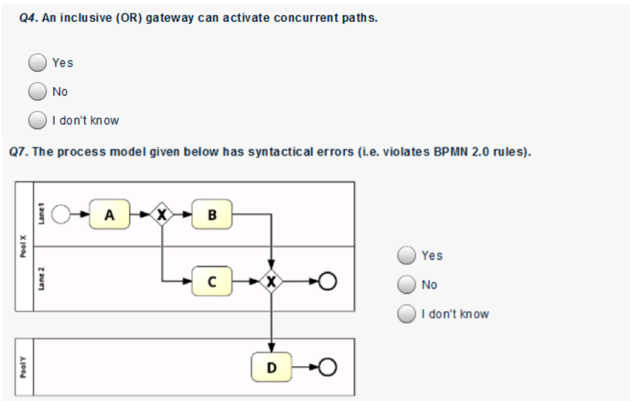


Fig. 3. Example questions from the test on theoretical knowledge on BP modeling and BPMN. (*the complete set of questions is available at: http://goo.gl/77YAxn*).

3.3 Process models used for the experiment

The process models that were used originated from real-life processes that were taking place in a large corporation headquartered in The Netherlands (which employs more than 115,000 employees and operates in over 100 countries worldwide). Among several processes in the company's quality management system, two processes of similar size and nature were selected taking into account their criticality in the business domain in which the company operates. The processes can be considered as large and rich in terms of the interaction taking place between different departments/divisions of the company (each process model incorporates 47 and 46 activity nodes, respectively, and 5 pools).

The selected processes were modelled in BPMN 2.0 based on existing process documentation, and on interviews with process owners and participants. The resulting models were BPMN collaboration diagrams, where the interaction between process participants was explicitly modeled using message flows. The models were subsequently reviewed by modeling experts for syntactical correctness, and validated for their correctness by the domain experts in the company.

These models are already used in our previous works to investigate also other factors of process model comprehension [13]. Accordingly, each process model was re-structured into two other forms, leading to *three forms of representation* for each process model. The first form is the fully-flattened one that shows a process model with all details at once (without the use of groups or sub-processes in BPMN 2.0). The second form makes use of the 'group' construct of BPMN that informally clusters a logically related set of activities on top of the fully-flattened form (similar to the use of 'expanded sub-processes' in BPMN 2.0). The third form uses collapsed sub-processes of BPMN 2.0 to create a one-level hierarchy of process models. A collapsed sub-process hides related parts of the model in the higher-level model, but can be accessed separately whenever the reader is interested in the information it contains. Fig. 4 shows an example model of one of the processes (process A) in the second representation form.

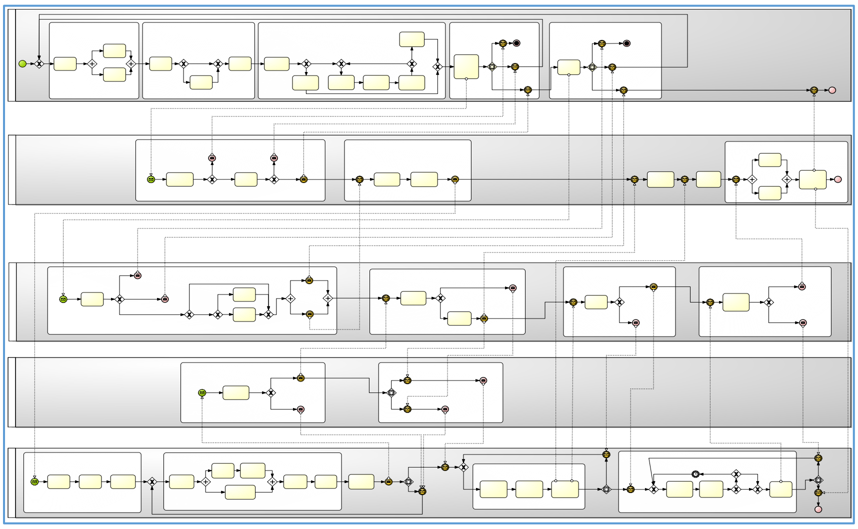


Fig. 4. Process A in *representation 2* (flattened with groups of activities). Note that the model is provided to give an indication of the size and structure of the model, and labels of all process elements are removed. These models were used also in our other experiments [13]. The complete versions of the models with labels are available online at: https://goo.gl/F9oHyg.

3.4 Measuring process model understandability

We used the *understandability task effectiveness* as a metric to quantify the level of understanding that the participants can demonstrate with respect to each process model [1, 31]. Understandability task effectiveness is operationalized by the understandability test score, determined by the number of correctly answered understandability questions for each process model. Accordingly, there was a need to develop a set of representative understandability questions in order to evaluate participants' level of understanding of the processes.

Together with the domain experts in the company, we developed 9 understandability questions for each process. The expert involvement is assumed to assure that each question can be used as a representative and valid way to assess someone's understanding of the processes. Since the quality of these questions has significant influence on the validity of the findings [32], particular attention was paid to develop a set of questions that is balanced in relation to different *process perspectives* (i.e. control flow, resource, and information/data), and different *scopes* (i.e. global and local). A *local* question can be answered by looking only at a single sub-process, while information available in the modularized (high-level) model is sufficient to answer a *global* question. Each question had a multiple-choice design, where respondents were provided with 5 options – the last one always being 'I don't know'. An example question for Process A is as follows:

Qn. If the planned actions for the CAPA are executed, who will receive the Execution Summary Report?

a) Only CAPA Manager
b) Only CAPA Review Board
c) Either CAPA Manager or CAPA Review Board
d) Both CAPA Manager and CAPA Review Board
e) I don't know (unable to tell)

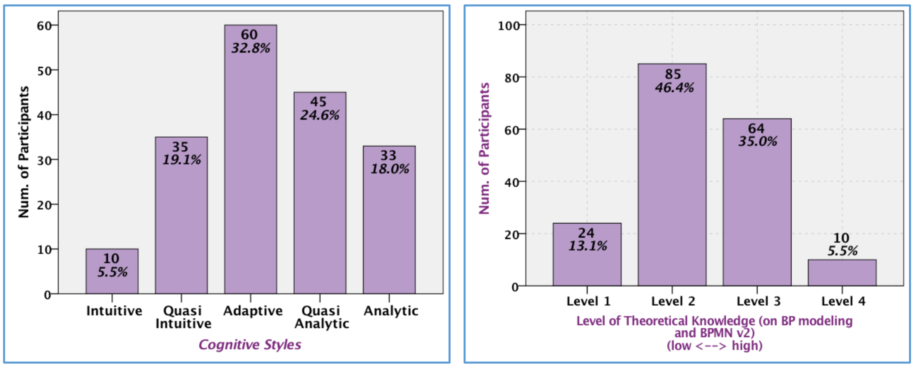
In total, we developed 18 understandability questions (9 for each process model, A and B). Each correctly answered question counts for 1 point for the score, totaling to 18 points max.

3.5 Participants of the Experiment and Blocks

The participants were graduate students of a number of engineering master programs; the majority of which were in operations management (64%), business information systems (14%), and innovation management programs (15%). These students were all enrolled in the same master level course on business process management (BPM), where they participated in the experiment as a final activity taking place few days before the final course examination. During the experiment, each participant was given two process models (A and B) in sequence in a different representation. The participants were randomly assigned to each experiment block.

4 Results

Fig. 5 presents the distribution of participants over the cognitive styles and the measured level of knowledge on BP modeling and BPMN 2.0. Accordingly, a high percentage of students are adaptive (32.8%), while the number of analytic thinkers (including quasi-) was higher than the intuitive thinkers. This was expected as the participants were students of engineering and/or technology master programs. As for the level of theoretical knowledge on BPM modeling and BPMN 2.0, the majority were at level 2 (46.4%), while only 5.5% were at level 4.



(a) (b)

Fig. 5. Number of participants with respect to (a) Cognitive Styles (as measured by CSI), and (b) BP modeling Knowledge Level (as measured by BPMC test) *(there were no participants at level 0 and level 5, i.e. who correctly answered 0-1, and 14-15 questions, respectively)*

We performed a correlation analysis between the CSI and the level of theoretical knowledge on BP modeling and BPMN 2.0, and found no significant correlation (with a Pearson correlation of -0.077 and p>0.29).

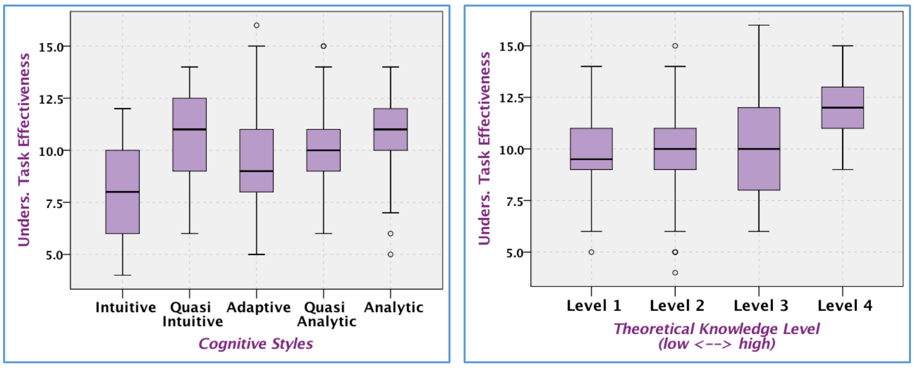
The overall mean score for understandability task effectiveness was 10.1 (out of 18) (st.dev: 2.38). Table 2 presents the descriptive statistics for the variables tested in the experiment. The boxplot diagrams for the understandability task effectiveness over the cognitive styles, and theoretical knowledge level are given in Fig. 6.

Table 2. Descriptive statistics.

Levels	**N**	**Understandability Task Effectiveness Score** *(Scale: 0 - 18)*	
Cognitive Style		**Mean**	**St.Dev.**
Intuitive	10	7.8	2.4
Quasi Intuitive	35	10.7	2.3
Adaptive	60	9.6	2.4
Quasi Analytic	45	10.2	2.2
Analytic	33	10.7	2.2
Theoretical Knowledge Level			
Level 1	24	9.7	2.2
Level 2	85	9.9	2.2
Level 3	64	10.1	2.7
Level 4	10	12.1	1.8

In order to identify the appropriate statistical tests that can be used for the testing of our hypotheses, we analyzed the data for conformance with the assumptions of possible statistical tests. The results showed clear deviations from *normality* for the measures of dependent variables over the independent variable (Kolmogorov–Smirnov and

Shapiro-Wilk tests of normality, all with $p < 0.01$). As a result, to evaluate our hypotheses we used a non-parametric test that does not pose assumptions regarding the normality of the data. In particular, we used the Kruskal-Wallis test with stepwise step-down comparisons [33].



(a) (b)

Fig. 6. Boxplot diagrams for Understandability Task Effectiveness over (a) Cognitive Styles, and (b) Theoretical Knowledge Level (on business process modeling and BPMN 2.0).

4.1 Hypotheses Testing 1: Cognitive Styles

Table 3 shows the results of our tests regarding the hypotheses.

Table 3. Results of the (Kruskal-Wallis) statistical tests.

	Understandability Task Effectiveness	
Independent Variables	H	p
Cognitive Style	15.55	*0.004**
Theoretical Knowledge Level	8.55	*0.036**

We argued in our first hypothesis that the understandability of a BP model is influenced by the model reader's cognitive style. The results of the Kruskal-Wallis test indicate that the effectiveness scores achieved from the understandability questions differ significantly due to the model reader's cognitive style [H(4): 15.55, *p=0.004*]. According to Kruskal-Wallis *multiple comparison*, the scores attained by *intuitive* thinkers are *significantly lower* than people that possess other cognitive styles. Moreover, the results show that, *analytic* thinkers score *significantly higher* than people with *adaptive* cognitive style. On the other hand, the difference between *quasi-intuitive*, *quasi-analytic* and *adaptive* thinkers is not significant.

The boxplot diagram given in Fig. 6(a) also signifies these effects. We observe a gradual increase in the understandability scores when traversing from intuitive to analytic thinkers, with the exception of *quasi-intuitive* thinkers. Based on the results, we speculate that a model reading task aligns better with analytical skills. In accordance with the cognitive fit theory [34], we can assume that the more a person's intrinsic cognitive style is analytical, the easier model reading task becomes for them, as they may suffer less from cognitive overload. However, we are currently not able to explain why scores from quasi-intuitive thinkers deviate from this linear tendency of increasing understandability as analytic thinking trait begins to dominate.

4.2 Hypotheses Testing 2: Theoretical Knowledge Level

The second hypothesis argues on the positive correlation between the understandability task effectiveness and model reader's level of theoretical knowledge on BP modeling and BPMN 2.0. According to the results presented in Table 3, at least one group of people with a certain level of theoretical knowledge scores significantly different than the other groups (that have different levels of knowledge) [H(3): 8.55, $p=0.036$].

The results of the Kruskal-Wallis *stepwise multiple comparison* indicate that the understandability scores achieved by people that are characterized as *level 4* (in terms of theoretical knowledge on business modeling and BPMN 2.0) are *significantly higher* than those that are achieved by people that have lower levels of theoretical knowledge. The difference between other levels (1 to 3), on the other hand, are not significant. The boxplot diagram in Fig. 6(b) also gives indication of this result. There is a need to increase the reliability and generalizability of these findings with more respondent data and a better measurement tool (a better version of the BPMC test).

5 Conclusion

In this paper, we found a significant relation of two personal factors (a model reader's cognitive style and theoretical business process (BP) modeling knowledge) to the level of process model understanding. Table 4 summarizes our findings with respect to our hypotheses. The results confirm earlier findings by Mendling et al. [12], which list theoretical BP modeling competency as a significant factor of model comprehension, but add the cognitive profile as an important factor.

The results from this exploratory experiment may help model readers to understand how they can develop themselves and may play a role in BPM team composition. Furthermore, the insights gained may also advance modeling tools and model representation environments. For example, because people with different characteristics show different levels of model understanding, one may consider to adapt model representations, modeling languages, modeling editors, modeling training, etc. to the different profiles of modelers or model readers.

Table 4. Summary of hypotheses tests.

Hypothesis	Result	Description
H1. The understandability of a BP model is influenced with model reader's cognitive style	*Supported*	- Intuitive thinkers score significantly lower than people with other cognitive styles. - Analytic thinkers score significantly higher than adaptive thinkers. - The difference between quasi-intuitive, quasi-analytic and adaptive thinkers is not significant.
H2. The understandability of a BP model is positively correlated with model reader's level of theoretical BP modeling competency.	*Supported*	- Participants with high theoretical knowledge (on business modeling and BPMN 2.0) score significantly higher than others with lower theoretical knowledge level.

For future work, we plan to refine current results by collecting more data, we plan to investigate the relation of other personal factors and cognitive profile measurements (such as learning style, field (in)dependency) with the level of process model understanding and we plan to investigate any moderating or confounding personal factors that potentially impact process model understanding.

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