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Findings from an Experiment on Flow Direction of Business Process Models

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Abstract: A core aspect of diagrammatic process modeling is the visualization of the logical and temporal order in which tasks are to be performed in a process. While conventions and guidelines exist that promote modeling processes from left-to-right or from top-to-bottom, no empirically validated design rationale can be provided for this choice so far. Therefore, this paper seeks to determine whether some flow directions are better than others from a cognitive point of view. We present the results of a controlled pilot experiment comparing the effects of four flow directions (left-to-right, right-to-left, top-to-bottom, bottom-to-top) on process model comprehension with a small sample size of 44 participants. Although there is a variety of theoretical arguments which support the use of a left-to-right flow direction as convention for process models, the preliminary empirical results of the pilot experiment were less clear-cut and showed that model readers also adapted well to uncommon reading directions.

Keywords: Model Layout, Reading Direction, Flow Direction, Business Process Models.

1 INTRODUCTION

Business processes describe which tasks need to be performed to reach certain business goals. Visual modeling of business processes is associated with several benefits such as a better understanding of the respective processes, improved communication between stakeholders, and easier identification of possible improvements. In general, diagrammatic process models are created using process modeling notations — i.e. sets of graphical symbols and rules for combining them — with the Business Process Model and Notation (BPMN) [BU13] being a de-facto-standard in that area. While such modeling notations also provide means to model actors or data involved in the execution of the process, in this paper we focus on the control flow logic describing the logical and temporal order in which tasks are performed. In particular, we are interested in different options to visualize the pre-defined order of process tasks. In essence, process modeling notations use node-link diagrams, a specific type of directed graphs to depict the process flow, viz. the execution order of tasks in a process. Thus, the position of the start and the end nodes as well as the arrowheads of the edges show the precedence relations between the model elements. From a cognitive point of view, such "arrows" are understood intuitively with respect to their causal and time-related meaning [TV00]. Still, there are

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various design options in which direction to “draw” the arrows and how to position the task symbols during modeling. Basically, there are four main options for the overall direction: left-to-right, top-to-bottom, bottom-to-top, right-to-left. While the modeling symbols are usually provided through the respective modeling tool and thus standardized via the corresponding notation, modeling direction is not predefined and users usually start modeling on a blank canvas [EJS11]. In this paper, our objective is to provide insights on how the choice of modeling direction will influence the readability of a model.

A considerable amount of literature has been published on cognitive effectiveness of modeling notations [e.g. MO09]. Several attempts have been made to transfer such insights to the area of business process modeling [GHA10], for instance with respect to different symbol sets including routing symbols of languages [see, e.g., FMS13, FRM13]. Moreover, layout factors such as modularization or line crossings and their impact on process model comprehension have been given considerable attention [EJS11, FKK13, RM08].

However, research has not yet sufficiently addressed the issue of modeling direction. [LA11] mentions the issue of direction in their layout guideline for BPMN diagrams and [FS14] makes a first effort to provide an overview of theories to predict which modeling direction should be optimal from a cognitive point of view favoring left-to-right orientation. However, empirical evidence for the superiority of a left-to-right orientation for process models is still missing, and to the best of our knowledge no empirical evaluation of flow direction has so far been undertaken. To close this gap, this paper reports on an pilot experiment in which we examined the influence of different flow directions on process model comprehension (with a focus on BPMN process models). This research question is important, because the “lack of commonly agreed publicly available guidelines” for style and layout of diagrams may impede quality of modeling tools and of resulting models [ES09]. Empirical foundations will enable the modeling community to establish sound guidelines concerning preferred modeling directions.

The remainder of this paper is structured as follows. The first part provides the theoretical background for our research. The next section describes the experiment we used to test our propositions. Subsequently, we present our data analysis and an examination of the results. Finally, the results are discussed from both theoretical and practical perspectives and we outline future research directions.

2 Background

While the *primary* (modeling) notation defines the concrete syntax of a language (the symbols and the rules for combining them), the *secondary* notation relates to “things which are not formally part of a notation which are nevertheless used to interpret it, such as conventions (e.g., reading a circuit diagram left-to-right and top-to-bottom)” [PE06, p. 293]. Thus, advice and recommendations concerning flow directions in process models can not only be found in standard documents, but also in layout guidelines or research articles. In contrast to other modeling languages, the BPMN standard document also mentions the flow direction aspect as a recommendation. In particular, the BPMN standard document [BU13, p. 40] gives the advice to either use a left-to right or top-to-bottom flow direction for modeling the sequence flow of a process model ("we also RECOMMEND that modelers use judgment or best practices in how Flow Objects should be connected so that readers of the Diagrams will find the behavior clear and easy to follow. This is even more important when a Diagram contains Sequence Flows and Message Flows. In these situations it is best to pick a direction of Sequence Flows, either left to right or top to bottom, and then direct the Message Flows at a 90° angle to the Sequence Flows. The resulting Diagrams will be much easier to understand."). However, since a recommendation is not compulsory, it is also important to take into account other literature on the use of flow direction for BPMN diagrams. The recommendation from the BPMN standard we quoted above is also picked up by one of the few available guidelines for layouting BPM diagrams on canvas [LA11]. Moreover, accompanying materials of the OMG standardization organization show that the BPMN example models are almost exclusively modeled left-to-right [BU13]. The convention to model from left-to-right is also reflected by different model layout algorithms. Such algorithms can be included in modeling tools to offer different layout options for orientation, alignment or spacing of elements. Therefore, information on modeling direction can also be found in research papers on layout algorithms for BPMN diagrams. For example, Effinger et al. [EF11] move the start symbol of a process model to the left-hand side and end events to the right-hand side in their layout algorithm. Likewise, [KI09] uses a left-to-right orientation in their layout algorithm for BPMN diagrams, and even gives a specific rationale for this choice: the match with "the horizontal progression of text in western handwriting".

Top-to-bottom direction seems to be less common than left-to-right, although some authors reported that the flow direction of BPMN diagrams is "usually top-to-bottom or left-to-right" [see, e.g., ESK09].

From a broader perspective, we also discuss how flow direction can be positioned in the overall context of layouting diagrams. Layout of diagrams can be applied on different design levels [ST12]: (1) there are layout principles relevant to all kinds of diagrams (e.g. Gestalt laws, minimizing number of overlapping objects), (2) principles relevant to graphs (e.g. minimizing line crossings, maximizing number of objects in flow direction, keeping uniform flow and edge direction in diagrams [ES09]) and (3) principles relevant to the specific type of diagram (e.g. aligning similar edges or consequences of a decision in a process diagram, placing task symbols right (and not under/above) a split gateway [KI09]). Flow direction as investigated in our study can predominantly be classified as belonging to the 3rd level (specific type of diagram in a specific notation), but also to the 2nd level (graphs in general). To a certain degree, our results might be generalizable to other kinds of directed graphs, since they face the same challenge to visually support the "inherent ordering of elements" by their visual flow [ST12].

As mentioned above, the BPMN standard and other guidelines do not clarify why left-to-right or top-to-bottom should be superior to other directions. In the following, we will draw on related disciplines such as cognitive research on diagram and graph perception to discuss potential effects of using different orientations.

Prior expectations and experience influence how people read diagrams and search for information in diagrams. Winn [WI82, p. 80] mentions that "diagrams convey information about sequences in two ways. First, English-speakers will tend to 'read' diagrams in the same way that they read language, from left to right and top to bottom. Diagrams not arranged in this logical sequence would lead to difficulty in information processing and to less learning. Second, lines and arrows can be used to suggest direction". There is a strong cultural influence of the direction of written language for reading and drawing diagrams. In the area of data models, a diagram type that does not have a predefined reading direction indicated by visual hints as arrows, Nordbotton and Crosby [NC99] showed via eye tracking experiments that users follow these "natural" reading strategies. On average, 60% of their participants followed a text-like reading strategy from left-to-right and top-to-bottom. (The other 40% followed an image-like reading strategy starting in the center followed by scanning in different directions.)

Understanding is easier if diagrams match user expectations and if they are consistent with previously learned diagram schemas [WI83]. Indeed, Winn [WI82] was able to demonstrate that for native English speakers it is more difficult to learn sequences in reversed-order (right-to-left) than in normal-order (left-to-right) diagrams. Similarly, research on flowcharts has shown, that directional orientation influences problem solution quality, time taken to view the charts and time taken to solve the problems [KR83]. Participants performed best when the orientation of flowcharts was consistent with the corresponding reading direction (best results for left-to-right, second-best results for top-to-bottom and worst results for right-to-left flowcharts). In those cases the participants made fewer errors and needed less time.

However, test subjects can develop "reversed diagram" schemas when working with reversed diagrams [WI83]. Winn found evidence for this phenomenon by investigating eye-movements in a study with right-to-left reversed diagrams. At first, participants performed worse in information searching tasks than participants with left-to-right diagrams. However, after four trials the participants adapted their perceptual strategy and no longer started looking at the upper left quadrant which contained little useful information. Winn concluded that if diagrams contradict usual schemas, they are more difficult to understand and provoke more errors in information search tasks at first, but an appropriate strategy can be obtained after time.

Studies in the field of cognitive science have further revealed that humans associate abstract semantic concepts with specific orientations (left, right, top, bottom). With respect to concepts that are relevant in the context of process modeling, the scientific literature shows that a clear preference exists to assign "earlier-later" to left-to-right followed by top-to-bottom and to assign "cause-effect" to top-to-bottom and left-to-right

[HD68, p. 354]. Based on these results it would be most naturally to design process models from left-to-right, and top-to-bottom is likely to be the second best option.

While it is not clear from the literature whether these internal associations between semantic concepts and spatial orientations are actually caused by conventions in visual representations (as diagrams, tables, or text) or vice versa, humans have chosen to use these conventions, because they seem more natural. A variety of examples demonstrate that specific semantic concepts are used predominantly with specific orientations. For instance, when looking at how temporal relations are represented in every-day life it is interesting to note that often top-to-bottom orientation is used (e.g. calendars, school schedules, programs, public transport schedules). Furthermore, in graphs time is often expressed from left-to-right on the horizontal axis [TKW91].

3 Hypotheses

Following from the theoretical discussion above, we will now advance propositions regarding the superiority of specific flow directions in regard to process model understandability. One of the essential arguments is that understanding a process model will be easier if its flow direction matches users' expectations [KR83, WI82]. Such expectations are formed by the direction of written language and typical conventions used in visual representations [TKW91, WI83]. Furthermore, humans associate specific semantic concepts with spatial orientations. Therefore, we suggest that flow direction will influence objective comprehension performance, as well as subjective experience of the comprehension task and the ease of use of the models. As the goal in our study is set at determining the optimal flow direction to contribute to a validation or challenge of existing conventions, we additionally want to address specific hypotheses on an optimal flow direction. In light of the above arguments, we specifically expect that left-to-right flow direction in a model is superior to other flow directions (top-to-bottom, bottom-to-top, right-to-left) with respect to process model comprehension. This is because it is consistent with text reading direction and the existing association between semantic concepts as "earlier-later" and left-to-right [HD68]. Therefore, we hypothesize:

- H1: Flow direction has an influence on process model comprehension accuracy.
  - H1a: Left-to-right flow direction in a model is superior to other flow directions concerning process model comprehension accuracy.
- H2: Flow direction has an influence on process model comprehension efficiency.
  - H2a: Left-to-right flow direction in a model is superior to other flow directions concerning process model comprehension efficiency.
- H3: Flow direction has an influence on the perceived ease of use of the model.
  - H3a: Left-to-right flow direction in a model is superior to other flow directions concerning the perceived ease of use of the model.

4 Research Method

4.1 Experimental Design

We conducted an experiment with model flow direction (with four levels: left-to-right, right-to-left, top-to-bottom, bottom-to-top) and label semantics (with two levels: abstract—text label, concrete—single letter) as two between-groups factors. The label semantics factor was added because for every language text has an inherent reading direction which might interact with the flow direction of the model. In addition, a text label adds additional cognitive load and increases the reading time and effort to assemble information in comparison to a label consisting of a single letter only [MSR12]. Therefore, we considered it important to use experimental groups with and without textual labels. As the approximate sample size requirement for analyzing this research design with an ANCOVA (and expecting medium effect sizes of $f(U) > 0.25$ with type-1 error probability of $\alpha < 0.05$ and sufficient statistical power > 0.80) would be 270 participants (calculated with G*Power 3 software [FA07]), we decided to first run a pilot study with a lower number of participants. Main advantages of pilot experiments are the possibility to evaluate the feasibility of the experimental design and to estimate the variability of differences between experimental groups prior to carrying out a full-scale experiment.

The pilot experiment took place in the context of information systems courses at a European university. In the following, we describe the paper-based questionnaire we used in our study. In particular, it was based on the questionnaire previously described in [FRM13].

4.2 Materials

The questionnaire included four main sections. The first section comprised questions about the participants' demographic data and prior knowledge on process modeling. In the second section we used the set of process modeling questions developed by Mendling and Strembeck [MSR12] to measure prior knowledge. The third section contained a tutorial on BPMN to inform participants about the meaning of the symbols and provided the participants with everything they needed to know to perform the subsequent comprehension tasks. The fourth section of the questionnaire displayed two different process models with eight corresponding comprehension tasks for each model. The models were drawn using basic symbols of the BPMN standard [FRM13, BU13].

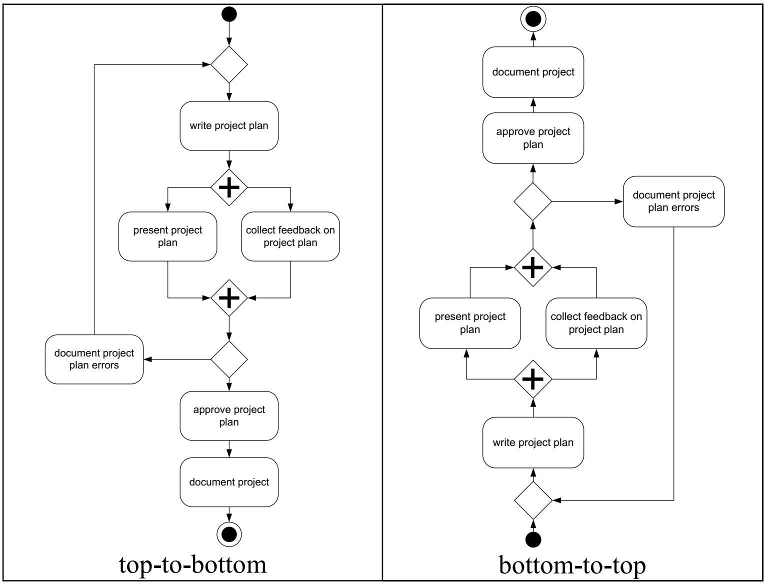
In the concrete labels condition, we used actual labels stemming from different domains (an emergency process plan for drinking water pollution with tasks such as 'control drinking water quality', or 'prepare information brochure' and a model on the marketing process in a company with tasks such as 'revise current marketing plan', or 'define quality criteria'). The reading direction for all labels was set horizontal left-to-right for all four experimental groups of differing flow directions, because reading speed for horizontal text is higher than for marquee or rotated text [YU10].

In the abstract label condition we used labels with uppercase alphabetic letters (e.g. ‘A’, ‘B’, ‘C’, ‘D’, etc.) in random order.

The comprehension tasks included questions on the control flow logic between pairs of tasks. In particular, the questionnaire included questions on concurrency (e.g. “[Task A] and [Task B] can be executed in parallel”), exclusiveness, order and repetition. ‘Task A’ and ‘Task B’ were substituted either by the concrete or the abstract label of the corresponding model. The comprehension questions had already been validated in a larger study on notional design and process model comprehension [FRM13].

Participants could answer the respective questions with ‘right’, ‘wrong’ or ‘I don’t know’. After each model we included a scale in which participants could rate the perceived ease of use of the models. The participants were allowed to spend as much time as desired for the completion of the experimental tasks and we asked them to write down the point of time at the beginning and the end of the comprehension questions.

To manipulate the “flow direction” factor in our experiment, we transposed the models to different directions and each experimental group was provided with one of the four flow directions — both models were modelled in the same flow direction. Fig. 1 shows an excerpt of four process models, which are structurally and informationally equivalent, but use different flow directions.



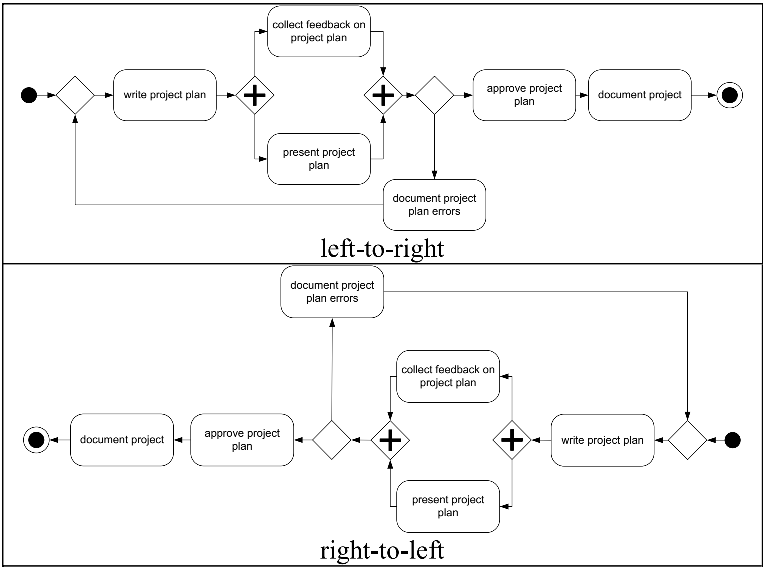


Fig. 1: Detail of a BPMN process model in different flow directions with concrete labels

4.3 Measures

Tab. 1 gives an overview on variables used in the experiment and their measurement.

Variable	Measurement
Comprehension accuracy (dependent variable)	Number of correct answers in the model comprehension tasks (8 comprehension tasks per model)
Comprehension efficiency (dependent variable)	Self-report completion time for the comprehension questions
Perceived ease of use of model (dependent variable)	4 items with a 7-point Likert scale (anchored between "strongly disagree" and "strongly agree") from Maes and Poels [MP07]
Process Modeling Knowledge (Covariate)	Process modeling test score: 8 items derived from Mendling and Strembeck [MSR12]

Tab. 1: Measurement of variables in the experiment

4.4 Participants and Data Screening

A total of 44 information systems students participated in this study. Half of participants (22) received the abstract label version, the other half (22) the concrete label version. There were 4-6 participants in each cell of the experimental plan (label semantics x flow direction). Of all respondents, 12 were female (27%) and 32 male (73%). The participants were on average 25 years old. 80% of respondents already had training in process modeling. To screen for possible differences between the experimental groups' demographics, we calculated variance tests, which yielded no problematic differences.

5 Results of the Pilot Experiment

In order to examine the data we collected on the hypotheses, we conducted four univariate analyses of covariance (ANCOVAs). We ran one ANCOVA each for the dependent factors comprehension accuracy (total score), comprehension efficiency (time) and perceived ease of use of the respective model. Flow direction and label semantics were used as independent factors and process modeling test score as covariate.

As can be seen from Tab. 2, no statistically significant differences were found between the investigated flow directions for any of the dependent variables. Thus, our hypotheses suggesting an influence of flow direction on process modeling comprehension accuracy (H1), efficiency (H2) and perceived ease of use of the model (H3) cannot be accepted. In addition, our analyses did not reveal interaction effects between flow direction and label semantics. Fig. 2 depicts comprehension accuracy for different flow directions.

Turning to the experimental evidence on process modeling knowledge, we observe from Tab. 2 that individual knowledge is a relevant influence factor for comprehension accuracy of the comprehension task. Higher individual process modeling knowledge is related to better performance in the comprehension task.

Label semantics did have a significant effect on the variable comprehension efficiency. On average, participants took over 1 minute longer to answer 8 questions on a model with concrete labels (5:36) than with abstract labels (4:02).

	Effect	**F** ($df_{\text{Hypothesis}}$; df_{Error})	**p**	**Partial eta squared**
Comprehension accuracy (Total score)	Flow direction	$1.77_{\text{df}=3;\ 36}$	0.17	0.13
	Label semantics	$0.28_{\text{df}=1;\ 36}$	0.60	0.008
	Process modeling knowledge	$27.64_{\text{df}=1;\ 36}$	**0.000**	0.43
Comprehension efficiency (Time)	Flow direction	$2.18_{\text{df}=3;\ 29}$	0.11	0.18
	Label semantics	$6.39_{\text{df}=1;\ 29}$	**0.02**	0.18
	Process modeling knowledge	$0.00_{\text{df}=1;\ 29}$	0.97	0.00
Perceived ease of use of model	Flow direction	$1.66_{\text{df}=3;\ 37}$	0.19	0.12

	Label semantics	$0.49_{df=1;\ 37}$	0.49	0.01
	Process modeling knowledge	$2.61_{df=1;\ 37}$	0.12	0.07

Tab. 2: Experimental results: influence of flow direction

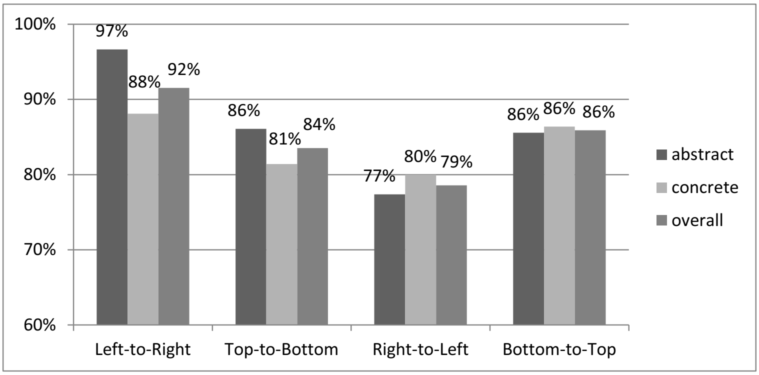


Fig. 2: Flow direction and comprehension accuracy

6 Discussion

The study presented in this paper set out with the aim of assessing the importance of flow direction in process model comprehension. We hypothesized that the use of the flow direction left-to-right would ease comprehension compared to unconventional flow directions, because of a cultural background of written language direction [WI83] and conventional use of left-to-right in diagrams from other areas [TKW91].

Our analyses revealed a number of interesting results. In contrast to our expectations, the experiment did not detect statistically significant evidence for a superiority of the left-to-right flow direction, although absolute comprehension values were highest. One other unanticipated finding was that the top-to-bottom flow direction did not outperform the bottom-to-top flow direction – absolute comprehension values were even slightly lower, although it is mentioned to be a second-best option in standard documents [BU13]. These results also differ from experimental results on flowcharts which indicate that top-to-bottom is the second best option after left-to-right [KR83]. Furthermore, our study found that uncommon flow directions such as bottom-to-top and right-to-left were not more difficult to understand than the conventional left-to-right direction. Right-to-left which is the sharpest contrast to the regular left-to-right reading direction did yield the lowest absolute comprehension values, although this difference was not statistically significant. It is possible though that this difference might be statistically significant with a larger sample size (92% overall comprehension accuracy vs. 79% in right-to-left) in the current sample).

These rather contradictory results concerning obviously uncommon flow directions (in specific, bottom-to-top) may be explained by the fact that when confronted with models, participants might have been especially cautious and also motivated to answer comprehension questions correctly as they perceived the task as a special challenge they wanted to solve. However, the models with the top-to-bottom flow direction lacked the aspect of an unusual challenge that would heighten participants' motivation, thus the cognitive disadvantage of being inconsistent with reading direction weighted stronger and could explain the lower performance of the top-to-bottom group. While any explanation of these unexpected results can only be speculative, it is worth noting that other researchers have found that people adapt surprisingly fast to uncommon reading directions in diagrams [WI83]. This is consistent with our results because a fast adaption of the participants to the uncommon reading direction might have resulted in the fact that we could not measure any performance loss for the corresponding flow directions. Further work on this topic could address the extent to which further model complexity of a process model would make the adaption to an uncommon reading direction more difficult. As the models used in the experiments had only included basic symbols to represent the sequence flow, they lacked complexity of models which model additional aspects such as message flows.

Moreover, other explanations for the result that left-to-right did not statistically outperform all other reading directions are possible. Empirical evidence has demonstrated that for reading tasks a left-to-right and a top-to-bottom bias exists in human attention [SH05]. The focus of attention is constantly shifted to the right/bottom while reading and the probability to search for information is higher for the direction of reading than to return to a previously scanned part. This "inhibition of return" bias is larger if the starting point for reading is presented on the left-hand side rather than on the right-hand side [SH05]. Thus, in the context of modeling this could mean that, compared to other directions, in the left-to-right flow direction, with a starting point on the left, people are less likely to move their attention backwards even in the case of a loop. This might lead to lower performance in understanding loops in models drawn from left-to-right and outweigh positive effects of familiar flow direction. Further research would be needed to validate if this explanation holds true though.

Because our experiment investigated BPMN models we also like to discuss an aspect concerning the generalizability for other process modeling notations. While we do believe that BPMN models are representative in terms of general visual characteristics of process models, a specific limitation to generalizability needs to be noted: BPMN XOR and AND routing symbols are constructed symmetrically. Results might differ if routing symbols are sensitive to rotation (as for instance in the UML, where AND is represented by a narrow rectangle (bar)) and would be presented from another angle when changing flow direction.

7 Limitations

As this paper presented a pilot experiment, a main limitation regarding statistical conclusion validity is the low sample size. We did not collect the suggested 20 observations per cell [SNS11] and also could not verify whether distribution assumptions of ANCOVA were met because of the low cell sizes. Therefore, the reported results must be interpreted with caution and it is too early to provide proof to contradict prior research.

In our data we noticed a ceiling effect as the comprehension scores piled up in the end of the scale. Such a restriction of range is a common threat to statistical conclusion validity.

One further source of weakness of this study is the selection of subjects. We recognize that the fact that our sample was drawn from information systems students with basic modeling experience might limit external validity. We do not know whether results can be generalized to experts in process modeling. In particular, it might be easier or harder for experts to adapt to uncommon flow directions. However, we believe that choosing a sample of students who were not biases by a high amount of prior exposure to a specific flow direction was consistent with the goals of the study to investigate the basic usefulness of different flow directions for modeling beginners.

8 Directions for Future Research

Further investigation and experimentation into flow direction of process models is strongly recommended. First, the presented pilot experiment needs to be replicated in form of a large-scale experiment with a higher sample size before the association between reading direction and process model comprehension is more clearly understood.

Second, it would be interesting to investigate not only consistent flow directions as done in this experiment, but also mixtures and changes of flow directions in the same process model. In practice, it can sometimes be noticed that people create “zigzag models” for instance in order to avoid the need for scrolling in a modeling editor or to fit a model to a specific paper format without having to reduce the overall size of model elements and labels. Moreover, right-to-left direction is often used in the context of loops; top-to-bottom and bottom-to-top are used when connecting tasks from different (swim)lanes. Thus, uncommon flow directions as right-to-left or bottom-to-top are in general not primarily used for a process model, but occur in practice in the context of directional changes in a model. We encourage future research to explore various forms of combinations of flow directions in models.

Third, further research might explore flow direction in the context of cultural differences. As reading directions differ across written languages, results might be different in other cultural areas.

Fourth, future research could address whether long experience with a modeling notation would lead to problems if a diagram is presented in an uncommon flow direction. Different notations often are connected to preferred flow directions. For example, UML activity diagrams and BPMN models are often seen with a left-to-right flow direction, while Event-driven Process Chains [SE00] are seen more often modeled from top-to-bottom.

9 Conclusion

To the best of our knowledge, the experiment reported in this paper is the first to investigate the effects of flow direction on process model comprehension. The findings from this pilot study serve as a valuable, first contribution to existing findings on process model layout and have implications for both process modeling practice and research. Moreover, the results have implications on secondary notation research in general. Our pilot study has been unable to empirically confirm a superiority of the left-to-right flow direction to other flow directions with respect to model comprehension, but we also found no negative effects of the left-to-right flow direction. Concerning the top-to-bottom flow direction, our preliminary results do not support a strong recommendation. However, a follow-up experiment with a larger sample size is needed to provide more definitive evidence.

Our findings support retaining existing modeling conventions suggesting left-to-right flow direction. From a theoretical perspective, we believe that advising left-to-right flow direction is beneficial.

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