Usability and Learnability of Graphical Notation Systems in Process Modeling Languages.

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Abstract
Modern working systems require a high amount of knowledge, communication, and cooperation. In order to capture, analyze and communicate internal knowledge, process-modeling methods (PMM) are applied which visualize processes in diagrams by using specific graphical notation systems. The learnability of PMMs largely depends on the individual PMM knowledge of employees, but also on process-specific knowledge about task elements, process routines, and required resources. Differing cognitive abilities might also hamper a correct understanding of process models. We present an evaluation study that assessed the comprehensibility and the learnability of a PMM notation system. The impact of user factors on learnability and comprehensibility of notation elements was analyzed. The findings show that the efficiency and the effectiveness of graphical notation systems depend on the degree to which user-centered design principles are carefully considered. Usability evaluation methods from the Human-Computer Interaction research were successfully applied to industrial contexts.

Keywords
Process modeling methods, notation elements, usability evaluation, learnability, user factors

1 INTRODUCTION

Since competition in the global market is increasing, the need for coordination of modern cooperative work systems is also growing. Business process management (BPM) is one way of meeting this challenge and improving process and service performance in companies [1]. Central element of BPM is the application of process modeling methods (PMM) in which business processes are visualized in process models by using specific graphical notation systems.

Though PMMs are widely used in many industrial contexts [2], their general usefulness and effectiveness are hampered by several factors: (1) the high complexity of PMM notation systems and process models which have to depict complex process chains (2), the diversity of the workforce that is supposed to acquire and apply PMM skills with its different cognitive qualifications regarding PMM experience, domain knowledge about process-specific task routines, cognitive abilities, etc.. In order to improve effectiveness, usability, and learnability of PMM, user-centered evaluation and design methods from Human Computer Interaction (HCI) research were applied to BPM.

2 PROCESS MODELING METHODS

Modern working and production systems require a high amount of knowledge, communication and cooperation between staff and organizational units. In order to assess, describe, organize and communicate internal business-specific knowledge, process-modeling methods (PMM) are applied which capture and analyze current business processes in process models. These process models contain information about operating resources, work materials, and staff activities. Advantages of PMM application are cost reduction and quality improvement, but also benefits in communication, motivation, and collaboration, as well as a mutual mental model of work procedures [3]. The increasing demand for PMM has led to a rapidly growing number of modeling techniques and tools (e.g. eEPC [4], UML [5], BPMN [6]). Since modern work and production systems increasingly require a high level of communication and cooperation [7], PMM should be able to map cooperative, highly interlinked work systems. One example of a PMM specifically designed for task modeling of cooperative work environments is the C3 method. The C3 method (C3 stands for "coordination", "cooperation", and "communication") is largely based on the Unified Modeling Language but was supplemented and enlarged by additional concepts and graphical notation elements for modeling cooperative work processes [7]. Due to its unique features regarding the modeling of cooperative and highly interlinked work systems, the C3 process-modeling method was chosen as object of investigation. Most of the C3 notation elements originate from UML, complemented by selected elements from Higraphs [8] and Task Object Charts [9]. Figure 1 shows a selection of exemplary elements of the C3 method.

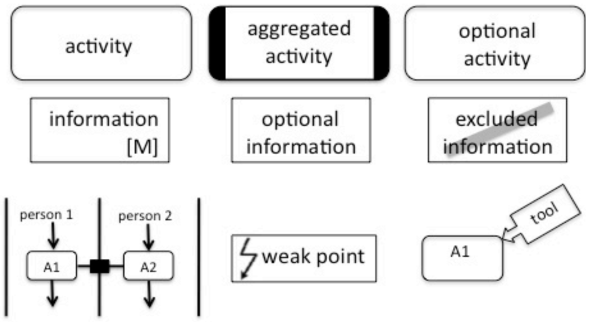

Figure 1 - Selected C3 notation elements.

Process models are visualized in diagrams or charts by using a specific graphical notation system which typically consists of a set of graphical elements (pictograms). These pictograms can be combined with each other according to a set of rules (syntax). Graphical notation systems of PMM consist of objects (such as activities, tools, information) and relations between objects (such as control flows, information flows, decisions). The visualization of work processes in process models is assumed to be more effective for further steps within the production chain [10], e.g., communicating the model to other workers or using the process model as a basis for computer simulations. Comprehensibility and usability of graphical notation systems are essential for effective communication and transfer of relevant knowledge into the work process. In reality, one of the biggest problems of process models is their poor transparency, understandability, communicability, and learnability [11]. At worst, process models – though pictorially designed in order to be universally understandable– have to be re-translated into textual form for a better understanding [12]. Intuitive comprehensibility and learnability are thus not intrinsic characteristics of PMM but require well-designed notation elements [13] and trainings.

3 INFLUENCES OF HUMAN INFORMATION PROCESSING AND PICTOGRAM ATTRIBUTES ON PERFORMANCE

Regarding human information processing, pictograms show many advantages in comparison to word signs or textual information: they are recognized, remembered, and learned more easily and they have a higher probability of being correctly interpreted in their meaning. However, the usage of pictograms also has disadvantages: only few pictograms are universally understood [14] and do not need extra learning effort; therefore, they may not be interpreted correctly by all user groups and across all cultures. Also, there is a high risk of significant confusion by interpreting the inappropriate meaning of pictograms [15][16]. The transfer of visually encoded diagrams (e.g., process models) in verbal or written codes (e.g., for job descriptions) is highly susceptible to errors as highly abstract visual information in process models has to be enriched by additional and contextualized information. Moreover, the correct interpretation of process models largely depends on the individual knowledge base of the recipient. This refers to a) knowledge about the specific process-modeling method and its related notation system, and b) process-specific knowledge about task elements, process routines, and required resources.

Problems in interacting with process models are not only caused by notation system characteristics but also by human information processing characteristics. Bottom-up and top-down-processes are assumed to interact in the identification, classification, and interpretation of notation elements. Semantic knowledge and mental representations stored in long-term memory are also involved in the perception of the perceived image into a meaningful and context-sensitive percept.

Accordingly, graphical representations such as process models are always perceived and interpreted based on the individual knowledge base of the users [15]. Apart from this, further individual variables such as differing mental models, cognitive abilities, or socio-cultural background might hamper the acquisition of PMM knowledge and a correct understanding of process models [16][17]. Especially users with restricted knowledge about a) PMM and/or b) domain-specific work processes (e.g., newly employed staff) might not be able to properly interpret single notation elements or complete process models.

Therefore, the present study reports on an empirical study in which the learnability and usability of the C3 notation system was evaluated. In order to support users in C3 knowledge acquisition and to account for user heterogeneity, a C3 training was delivered and learning effects for the C3 notation system were quantified and related to individual user factors (cognitive abilities).

4 METHODOLOGY

4.1 Empirical Procedure

In the beginning of the study demographic information (age, education, PMM-experience) and cognitive abilities were assessed by applying psychometric tests (spatial visualization, flexibility of closure, associative memory and visual memory). Before participants received the C3 training, they rated the pictorial and semantic transparency of 25 C3 notation elements (t1: pre-training, interpreted as baseline performance, Figure 2).

Following the C3 training, participants were requested to evaluate the semantic transparency of C3 notation elements again (t2: post-training), and ratings of learnability, comprehensibility, ease of use, and usefulness were collected. Since the C3 training focused on the understandability (semantic aspects) of C3 notation elements (as this is the most decisive cognitive process in real world environments), we abstained from an assessment of the visual quality (pictorial transparency) in t2 and concentrated on semantic transparency only. (This also reduced the duration of the experiment as the whole experimental session already took approximately 2h.)

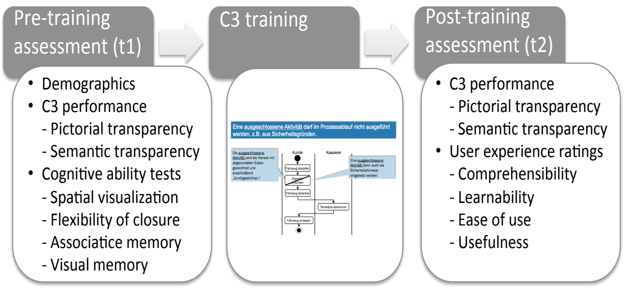

Figure 2 - Experimental procedure.

4.2 C3 Training

The C3 training was provided in form of a written manual (30 pages) which contained an introduction with a short description of PMM in general and the origins of the C3 method (8 pages), as well as explanations for the single C3 notation elements (22 pages). For each notation element, the graphical representation and semantic meaning were explained, supplemented by a concrete practical application example and further comments. For each notation element cluster, participants accomplished a training task in which short processes were modeled by using the C3 notation elements. No time limit was given to study the C3 manual and participants were allowed to ask the experimenter (a C3 expert) for further information in case of comprehension problems.

4.3 Variables

To assess the visual quality and the *pictorial transparency*, the participants were asked to describe, what – according to their view – the pictogram would visualize ("what does the pictogram show?)". Assessing the clarity of the pictogram's meaning, the *semantic transparency*, participants had to write down the semantic concept of each notation element ("what does the pictogram mean?").

As *dependent variables* the proportion of correctly described pictogram appearances (for pictorial transparency) and pictogram meanings (for semantic transparency) was measured. Two experts independently carried out the assessment of participants' replies regarding the pictorial and semantic content of pictograms into "correct" and "incorrect" answers. For the analysis of results, we referred to the DIN ISO norm (9186) for icon design [18]. According to that, an icon revision is recommended if identification rates for a specific icon are below 66%.

For the psychometric assessment of cognitive abilities, the Kit of Factor-referenced Cognitive Tests was applied [18]. The following abilities were measured: spatial visualization ability, i.e., "the ability to manipulate or transform the image of spatial patterns into other visual arrangements" (paper-folding test, VZ-2), flexibility of closure, i.e., "the ability to 'hold in mind' a particular visual percept (configuration) and find it embedded in distracting material" (hidden figures test, CF-1), associative memory, i.e., "upon presentation of one part of previously associated but otherwise unrelated material, ability to recall another part" (associative memory test, MA-1), and visual memory (shape memory test, MV-1).

In order to capture user experiences of C3 interaction, comprehensibility, learnability, ease of use and usefulness of C3 notation elements were assessed. Participants had to rate comprehensibility and learnability of each notation element on 6-point Likert-scales (1 = very low to 6 very high). After the training they rated ease of use and usefulness-items (12 items in total on a 5-point Likert-scale). For comparability reasons, user perception ratings were transformed into % values.

4.4. Sample

A total of 22 participants aged between 21 and 35 took part in the study (M = 26.7 years, SD = 3.8,). The sample consisted of engineering students and engineers with domain knowledge: the majority (90%) reported to have theoretical and practical knowledge about process modeling languages.

5 RESULTS

5.1. Usability of the C3 notation system - Pre-Training Performance

5.1.1 *Pictorial transparency of C3 notation elements (t1).*

The visual quality (pictorial transparency) of the C3 notation system was, on average, 86.2% (SD = 19.31, range 32-100%), which indicates a high pictorial transparency of the C3 method.

Looking at the pictorial transparency of single C3 notation elements, the average performance was above the DIN-recommended cut-off of 66% (see Table 1, middle column). The highest pictorial transparency was about 100% for the elements "start" and "further activities", the lowest pictorial transparency was found for the element "synchronization bar" with 70%. To sum this up: C3 notation elements do not require a pictogram redesign due to their transparent visual-graphical design characteristics.

5.1.2 Semantic transparency of C3 notation elements (t1).

Semantic transparency of the C3 notation system was about 58.4% (SD = 11.04, range 40-76%) which indicates a rather low semantic transparency and intuitive comprehensibility. The high level of abstraction of C3 elements and the semantic distance between the pictorial quality of the C3 elements and their semantic meaning might explain this finding. On the single C3 element level (see Table 1, right column), semantic transparency ranged from very low for the elements "aggregated activity" (5%) and "information flow" (10%) up to very high for the elements "activity", "control flow", "excluded object", and "optional object" (all 100%).

C3 elements	pictorial transparency (t1)	semantic transparency (t1)
activity	90%	100%
aggregated activity	80%	5%
blob	90%	85%
control flow	95%	100%
decision	90%	85%
end	90%	65%
excluded activity	90%	70%
excluded information	90%	45%
excluded object	75%	100%
further activities	100%	75%
information	90%	50%
information flow	95%	10%
iteration	75%	95%
object	80%	5%
optional activity	85%	75%
optional information	90%	35%
optional object	80%	100%
parallel composite activity	80%	45%
sequential composite activity	80%	40%
start	100%	70%
swimlane	95%	95%
synchronization bar	70%	90%
synchronous cooperation	75%	80%
tool	85%	85%
weak point	85%	55%

Table 1 - Percentage of correct answers regarding pictorial and semantic transparency of C3 notation elements in t1 (alphabetical order)

In summary, the semantic transparency of the C3 notation system is rather low, especially in comparison to its pictorial transparency quality. Therefore it was of central interest to find out if semantic transparency could be improved after receiving the C3 training.

5.2 Learnability of the C3 notation system - Post-Training Performance

As effect of the C3 training, semantic transparency performance significantly increased from 58.4% (SD = 11.0) to 87.2% (SD = 9.3; $F(1,19) = 132.03$, $p < 0.000$). Regarding learning effects for single C3-elements, Table 2 shows semantic transparency performance in t2 (middle column) and the learning effect in comparison to t1 for each C3 notation element (right column).

The knowledge gain ranged from 0% for elements which already possessed a high semantic transparency (e.g., "activity", "tool") to above 40% (e.g., "excluded information", "parallel composite activity") and reached a maximum of 80-85% ("object", "aggregated activity"). Contrary to expectations, the C3 training had a negative effect on some C3 elements, as the decrease in semantic transparency performance indicates ("control flow", "excluded object", "optional object", "swimlane", "synchronization bar").

Summarizing so far, the C3 training effectively supports participants in acquiring semantic C3 knowledge.

C3 elements	semantic transparency (t2)	learning effect in %
object	90%	85
aggregated activity	85%	80
information flow	95%	55
optional information	90%	55
sequential composite activity	95%	55
information	95%	45
excluded information	85%	40
parallel composite activity	85%	40
end	100%	35
weak point	90%	35
start	100%	30
excluded activity	95%	25
optional activity	100%	25
blob	100%	15
decision	100%	15
further activities	90%	15
synchronous cooperation	90%	10
iteration	100%	5
activity	100%	0
tool	85%	0
control flow	95%	-5
swimlane	85%	-10
synchronization bar	80%	-10
excluded object	75%	-25
optional object	75%	-25

Table 2 - Percentage of correct answers regarding semantic transparency and learning effects for C3 notation elements after the C3 training (t2)

5.3 Impact of user factors on C3 training performance

The comprehensibility (measured by pictorial and semantic transparency performance in t1) and learnability (semantic transparency performance in t2) of the C3-notation system was not significantly associated with users' cognitive abilities, as correlational analyses showed (Table 3).

	spatial visualization ability	flexibility of closure	associa-tive memory	visual memory
pictorial transparency (t1)	.07	-.34	-.05	.19.
semantic transparency (t1)	-.36	.33	-.12	-.04
semantic transparency (t2)	-.38	.07	.26	.20

Table 3 - Correlations between pictorial and semantic transparency and cognitive abilities

5.4 User perceptions of the C3 notation system and the C3 trainings

Finally, participants were asked to rate the comprehensibility of notation elements as well as the learnability, the ease of using the elements and the perceived usefulness of the notation system. As found, comprehensibility and learnability of the C3 notation system after the C3 training was positively evaluated. The comprehensibility was rated on average with M=81.2% out of 100% (SD = 7.6, range 67.3 – 96.0) and learnability with M=90.4% (SD = 5.4, range 78.7 – 96.0). Ease of use was on average M=88.0% (SD = 7.6) and usefulness of the C3 system was on average M=75.3 (SD=13.7).

6 CONCLUSIONS

In the present study, established HCI icon evaluation methods were successfully transferred and applied to the context of PMM. Once again it was found that industrial applications and processes do distinctly profit from a cognitive-ergonomic evaluation based on usability methodologies. By applying these user-centered evaluation and design methods, valuable insights regarding C3 element optimization needs could be discovered. Since graphical notation systems of PPMs have never been investigated from a user perspective so far, the analysis of the pictorial and semantic transparency of notation elements appear as a promising way to integrate users into the research- and design process of graphic notation systems.

The comprehension of the C3 notation elements was considerably affected by individual experience with process modeling methods. Interestingly, general knowledge of PMM is not fully sufficient for a correct understanding of C3 notation elements. Although general domain knowledge about process-modeling methods benefits the recognition of C3 notation elements, it does not lead to identification rates demanded by the ISO standard. Apparently, general PMM-experience cannot be easily transferred to the C3-method.
In short: C3 is not intuitively applicable or learnable, especially for novices, which is due to icon complexity and the arbitrary icon character. Semantic distance is the best predictor of performance as it relies on "goodness of fit"-assumptions between pictograms and their assumed functions rather then their pictorial characteristics and visual quality [20]. Overall, semantic distance is more decisive for users' understanding than the concreteness of the icon itself because the semantic distance accounts for a wider range of icons that are not necessarily pictorial and may be quite abstract [21] [22].

For a successful identification and application of C3 notation elements, specific C3-experience is necessary, which, however, can be easily delivered by prior training sessions with the users. As shown, the C3 training proved to be highly successful as taken from the huge learnability effects and the positive user perceptions after the training.
In contrast to expectations, the impact of cognitive diversity on performance outcomes was comparably low. Thus we can conclude that the C3 notation system is comprehensive, learnable, and applicable for *every* user – independent from his/her cognitive predispositions ("design for all").

As final conclusion, the findings concordantly show that the evaluation and the design of graphical notation systems of PMM should be harmonized with mental models of PMM-users [23].

Methodologically, this aim can be achieved by pursuing a detailed, user-oriented empirical procedure that analyzes the adequacy of graphical notation systems under consideration of application contexts and individual characteristics of the target group. This evidence-based "bottom-up-approach" is a promising way to develop graphical notations which are "designed for all", i.e. independent from differing levels of experience with process modeling methods.

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8 BIOGRAPHY

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