A Survey-based Analysis of Principles to Evaluate Visual Notations of Process Modeling Languages

Abstract. Process modeling languages such as BPMN or EPC provide a set of graphical constructs defining their visual notations. The visual notation is one comparison criteria in favor of a process modeling language. Usually, the first choice for the evaluation of visual notations are the principles of the Physics of Notation (PoN) theory. Their vague operationalization, however, gives room for contradictory recommendations how to improve visual notations. Therefore, the intention of this paper is to identify recent empirical studies to visual notations of process modeling languages, which might contribute to a better understanding of PoN principles. A comprehensive literature survey has been conducted showing a confirmation of the PoN principles and identifying refinements for their operationalization. We applied our findings to an evaluation of the visual notation of BPMN from 2012 and showed advancements. Our findings define the current guidelines for evaluating and improving visual notations of process modeling languages.

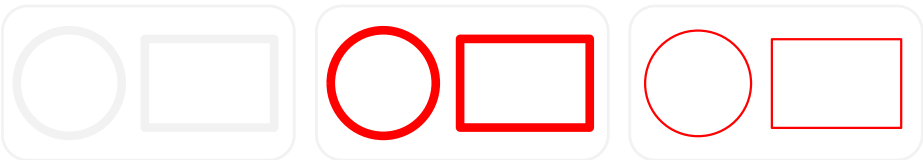
Keywords: Process modeling languages, Physics of Notations principles, understandability, cognitive effectiveness, visual notations

1 Introduction

Plenty of modeling languages exist to design business processes with different representations (e.g., text vs. graphics) or using a different design paradigm (e.g., imperative vs. declarative process modeling languages).

The decision in favor of a process modeling language can be made based upon the comparison of the semantic representation of the process modeling languages [1], [2], their practical acceptances [3], case studies [4] or the cognitive effectiveness of the visual notations [10]. To compare the *visual notation* of process modeling languages, the Physics of Notation (PoN) principles by Moody [5] are usually consulted as the first choice [6]. The principles "*can be used to evaluate, compare, and improve existing visual notations as well as to construct new ones*" [5]. Further language evaluation frameworks exist such as the Cognitive Dimensions of Notations [7] or the semiotic quality (SEQUAL) framework [8]. However, it has been shown that several limitations disqualify both frameworks for this purpose [9], [10]. Also the Bunge-Wand-Weber ontology [11] is not appropriate for this evaluation since it defines a framework for representational analysis of process modeling languages and excludes visual representation aspects [12].

PoN bases on nine principles, which were synthesized from theory and empirical studies. Although the PoN principles are widely accepted, their vague formulation and operationalization give room for contradictory recommendations how to improve visual notations. Contradictions in the evaluation arise due to different user context or exogenous factors (e.g., culture).



visual notation 1 visual notation 2 visual notation 3

Figure 1: The vague formulation of how pop-ups for constructs can be achieved gives room for misinterpretations exemplified on associations between color and culture and color and brightness.

For instance, Figure 1 shows three visual notations defined by two symbols. The symbols are equivalent in terms of shape and size but differ in color and brightness. Imagine these symbols define constructs of a process modeling notation (e.g., rectangles represent activities and circles represent conditions). According to the *Visual Expressiveness* principle, which addresses the range of used visual variables (i.e., size, orientation or color), a different benchmark would result for this principle when users with different cultural context evaluate the symbols. In China the red color is associated with luck while in European the red color is associated with danger/importance. Moody mentions this (intuitive) aspect of color. However, recent empirical studies show that color helps to distinguish symbols and that even red color can support visual communication. Also new insights show that users might be hampered to discriminate the symbols due to an interrelation between color and brightness leading to a different evaluation benchmark.

The intension of this paper is to analyze empirical studies and observations (published after the publication of the PoN theory in 2009) addressing visual notations of process modeling languages. An initial attempt exists formalizing the PoN principles. However, this formalization is based on the suggestion of Moody from 2009 [13]. Related, recent insights to visual notations are unconsidered in [13], which we identified within a literature survey. The literature survey presented here has two main benefits:

- It can be considered as a catalogue of guidelines to operationalize visual notations. Such guidelines promote the development of process modeling languages and tools resulting in a better communication between different roles.
- Our analysis concretes PoN, intends to minimalize the gap for misinterpretations and points to PoN principles still requiring empirical investigation.

The paper is structured as follows. The next section summarizes the PoN principles. The literature review examining empirical studies and new analysis regarding visual notations of process modeling languages is described in Section 3. Section 4 relates the literature to the PoN principles pointing to complements of PoN. Section 5 applies this PoN complements to BPMN showing how our findings advance evaluations of the visual notation of BPMN. The paper ends with a conclusion and an outlook.

2 Summary of “Physics of Notation”

Moody studied various theories and defined a descriptive theory for visual notations. He argues that a visual notation can only be improved when understanding *how* and *why* visual notations communicate. Particularly, two complementary processes define communication, which are encoding (expression) and decoding (interpretation). The visual notation supports to encode a process model or diagram respectively and should be understood by the sender (e.g., process owner) and the receiver (e.g., business analyst). Understandability is hampered by noise (i.e., unintentional use of visual variables), which thus should be minimized.

To improve the cognitive effectiveness of a visual notation Moody suggests nine principles shown in Table 1. Cognitive effectiveness is defined by speed, ease and accuracy with which the human mind processes. The principles influence each other positively or negatively and so trade-offs can occur. For instance, the increase of constructs (addressed by *Graphic Economy*) hampers discrimination (addressed by *Perceptual Discriminability*). Users are handicapped by too much constructs.

Table 1: Principles and Operationalization of Physics of Notation

1. Semiotic Quality	Principle: A one-to-one correspondence should exist between graphical symbols and semantic constructs, i.e. each symbol should represent one semantic meaning and vice versa.
	Operationalization: *1.1* *Symbol redundancy:* multiple graphical symbols represent same semantic construct. *1.2* *Symbol overload:* different constructs are represented by the same symbol (ambiguity). *1.3* *Symbol excess:* symbols don't correspond to semantic constructs. *1.4* *Symbol deficit:* semantic constructs are not represented by symbols.
2. Perceptual Discriminability	Principle: Symbols should be clearly distinguishable from one another.
	Operationalization: 2.1 *Visual distance:* number of visual variables on which they differ and the size of these differences. 2.2 *The primacy of shape:* extend of shape variation. 2.3 *Redundant coding:* using multiple visual variables to distinguish between them. 2.4 *Perceptual popout:* each graphical symbol should have a graphical value on at least one visual variable. 2.5 *Textual differentiation:* symbols should be differentiated using visual variables, so that differences can be detected automatically and in parallel by the perceptual system.
3. Semantic Transparency	Principle: Use visual representations whose appearance suggests their meaning.
	Operationalization: *3.1* *Perceptual resemblance:* use of icons to make diagrams more visually appealing. *3.2* *Semantically transparent relationships:* applies to representing relationships.
4. Complexity Management	Principle: The model should have mechanisms (e.g.: hierarchy structures) feature, with which the complexity depending on the demand can be adjusted.
	Operationalization: *4.1* *Modularity:* divide systems into smaller parts or subsystems. *4.2* *Hierarchy (levels of abstraction):* represent systems at different levels of detail.

5. Cognitive Integration	Principle: If the process consists of several models, there should be mechanisms to include information from other models (see. Complexity Management). Operationalization: 5.1 *Conceptual integration:* mechanisms to help the reader assemble information from separate diagrams into a coherent representation of the system. 5.2 *Perceptual integration:* perceptual cues to simplify navigation and transitions between diagrams
6. Visual Expressiveness	Principle: To increase the visual expressiveness of each icon, the full range of visual variables should be used. Operationalization: *6.1* *Use of colors:* use of color for redundant coding *6.2* *Choice of visual variables:* choice should not be based on arbitrary but on the nature of information to be conveyed. *6.3* *Textual vs. graphical encoding:* graphical encoding should be preferred to textual encoding.
7. Dual Coding	Principle: The model should be complemented with text to address both cognitive channels. Operationalization: *7.1* *Annotations:* including textual explanations improve understandability *7.2* *Hybrid (graphics + text) symbols:* textual encoding can be used to reinforce and expand the meaning of graphical symbols.
8. Graphic Economy	Principle: The number of symbols should be limited to a cognitively manageable number. Operationalization: *8.1* *Reduce (or partition) semantic complexity:* simplify the semantics of a notation. *8.2* *Introduce symbol deficit:* choose not to show some constructs graphically. *8.3* *Increase visual expressiveness:* increase human discrimination ability.
9. Cognitive Fit	Principle: Depending on the circumstances (e.g., task and target group), the model should offer different representations. Operationalization: *9.1* *Expert-novice differences:* develop representations that are understood by both business and technical experts. *9.2* *Representational medium:* use of different representational media.

3 Literature Review

This section summarizes a literature review addressing contributions to visual notations of process modeling languages and PoN principles intending to answer these two questions:

- **RQ 1:** Which PoN principle could be confirmed by empirical studies?
- **RQ 2:** Do new insights exist to operationalize and to concrete the principles?

The selected databases used for the literature analysis (cf. Table 2) cover a broad field of scientific disciplines (SCIENCE DIRECT, ISI WEB OF KNOWLEDGE) as well as emphasize Computer Science (SPRINGER) and Economics (EBSCO) and in sum cover approx. 950.000 journals, books and conferences. A systematic literature review was performed for publications between 2009 and 2016. The following query was used:

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("visual notation" OR "cognitive quality" OR
"understandability" OR "physics of notation" OR
"empirical study" OR "cognition" OR "semiotic quality" OR
"perceptual discriminability" OR "semantic transparency"
OR "complexity management" OR "cognitive integration"
"visual expressiveness" OR "dual coding" OR
"graphic economy" OR "cognitive fit")
AND
("process modeling language" OR
"process modeling notation")
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Two persons searched for related literature. Although, the query was restrictive, SCIENCE DIRECT, EBSCO and ISI WEB OF KNOWLEDGE still returned plenty of irrelevant papers. Papers were selected as relevant if they addressed visual notations of process modeling languages and made a contribution to their evaluation or improvement. The following papers were thus excluded:

- Application of PoN to other notations or domains than business process engineering. This excludes e.g., papers describing the application of PoN to UML (class diagrams) [14] or the ER notation. Insights from other modeling notations cannot be directly applied to process modeling notations because they differ in theoretical foundation of symbols impacting human's perception.
- Plenty of papers exists describing empirical studies on business process model understandability such as the influence of routing constructs or the use of colors to highlight the control-flow. These insights are essential, however, with respect to the research focus of the paper (influences on the visual notation of process modeling *languages*) these papers were not further considered.
- Papers that partially addressed an operationalization of a principle, but not the PoN principle in general. For instance, empirical studies are available to evaluate the usefulness of process model hierarchies. The construct of "model hierarchy" is addressed by PoN 4.1 but since the intention of principle 4 is towards "mechanism

features", such papers do not fulfill the general intention of principle 4 or PoN. It would make sense to conduct a second bottom-up survey investigating influences on process models and modeling languages.

Table 2 lists the papers that were retrieved with the query.

Table 2: Summary of literature query

Source	Restriction and settings	Hits
Springer Link	Include Preview-Only content	33
Science Direct	All Sources	112
EBSCO Host	Databases: All; Field: TX All Text	213
ISI Web of Knowledge	Field: Topic	148
Addition of papers	Extension of the result set by forward- and backward search	218
HITS FROM	*Sum or reviewed papers*	***724***
ALL HOSTS	*Selection of relevant papers from the hits*	***14***

Table 3 shows the list of selected papers used as foundation to respond to RQ1 and RQ2. Most of the papers (80%) refer to PoN by an empirical study, two papers [21], [24] deduce observations to visual notations from literature and one paper applies observations to evaluate visual notations of process modeling languages [25].

Table 3: List of related literature

Ref.	Year	Type	Title of research work
[15]	2012	e	How novices design business processes
[16]	2012	e	Making Sense of Business Process Descriptions: An Experimental Comparison of Graphical and Textual Notations
[17]	2013	e	The Influence of Notational Deficiencies on Process Model Comprehension
[18]	2013	e	A study on the effects of routing symbol design on process model comprehension
[19]	2013	e	Visual notation design 2.0: towards user comprehensible requirements engineering notations
[20]	2013	e	Visually Capturing Usage Context in BPMN by Small Adaptations of Diagram Notation
[21]	2015	a	Business Process Modeling Support by Depictive and Descriptive Diagrams
[22]	2016	e	Process innovation as creative problem solving: An experimental study of textual descriptions and diagrams
[23]	2016	e	Influence factors for local comprehensibility of process models
[24]	2016	a	Perceptually discriminating Chunks in Business Process Models
[25]	2016	o	Essential elements of business process modeling
[26]	2016	e	Towards a Marketplace of Visual Elements for Notation Design
[27]	2016	e	User Involvement in Applications of the PoN
[28]	2016	e	Enhancing understandability of process models through cultural-dependent color adjustments

Legend: e=empirical study; o=observation; a=application of theory

To understand the relationships between the related literature and Moody [5], we investigated two further questions:

(1) Did the papers refer to the Physics of Notation paper by Moody?
(2) How does the citation network look like for these papers?

The intention of the question (1) was to investigate if the authors intended to contribute to PoN. Figure 2 shows the results. Except of three papers, PoN was cited. Authors of the papers [22] and [23] referred to PoN in their prior papers [17], [18]. Thus, an indirect reference to PoN by papers [22] and [23] might be concluded. Paper [25] does not refer to PoN or any theory on visual notations and it describes only observations meaning that its observations should be accepted with caution.

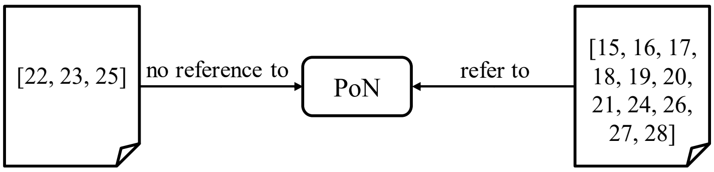

Figure 2: Citation of PoN in related literature

Next, we investigated the citation network of the papers. The results are shown in Figure 3. The citation density[1] of the literature is 10,8%, which can be considered as weak. The papers did not refer to findings of each other. The reason for the missing references might be the year of publication. Most of the papers were published in 2016 and thus the authors of papers from 2016 might not have been aware of other related papers due to a temporal overlap.

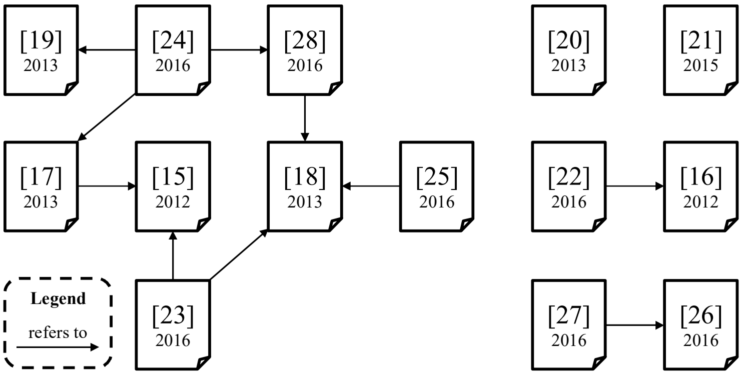

Figure 3: citation network of related literature

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[1] Number of ingoing arcs to a reference where one ingoing arc means one citation by the paper. For instance, paper [15] was cited twice (by paper [17] and [23]).

To sum up the literature review: papers making recommendations to visual notations of process modeling languages generally made their suggestions referring to PoN principles. This might be considered as an acceptance of PoN.

4 Analysis of the literature review

To understand the contributions of related literature to PoN, we analyzed the literature regarding *RQ1* and *RQ2* (see page 6). Table 4 summarizes the analysis. First, we excerpted the main statement(s) of the paper. Next, we analyzed if the paper confirmed the PoN principles (column *RQ1*) where “ ∨ ” means explicit confirmation of PoN and “ – “ means no confirmation. If new insights regarding visual notations were stated in the paper, then “ + ” and the number of principle(s) being addressed were added to the last column. For instance, 3.1 means that principle *Semantic transparency* and particularly *Perceptual resemblance* was addressed.

Referring to *RQ1*: The papers [15-19], [24] and [28] indicate a confirmation of the principles of the Physics of notation theory. Papers [21-23] and [25-26] did not address or confirm a PoN principle but provided novel ideas how to influence visual notations of process modeling languages.

Table 4: Classification of related literature based on RQ1 and RQ2

Ref.	Main Statement	RQ1	RQ2
[15]	• Increased use of graphics leads to a decreased process design quality • Text labels combined with abstract graphical forms works best • Flowchart design was the most favored type of design	∨	+ 3.1
[16]	• Participants from all groups who first read written use cases benefited further from the BPMN set.	∨	+ 7.2
[17]	• Research should either study notational, syntactical, and semantic aspects of modelling languages independently or integrate them as separate treatments • Quantitative measure for visual discriminability of a symbol set (EPCs with six notational elements than for BPMN with its more than 30 event types alone) → it seems recommendable to use symbol sets without global notational deficiencies	∨	+ 8.2
[18]	• Our factor analysis of the user evaluations of the symbols confirm that the criteria perceptual discriminability, semantic transparency, pop out and aesthetics are perceived as independent dimensions: user evaluation procedures for symbol choice → use well known symbols known from other domains (e.g., mathematics) to allow for positive transfer effects.	∨	+ 2.3 2.5
[19]	• Visual notation design should be conducted by large numbers of novices (crowdsourcing-based approach).	∨	+ 9.1
[20]	• Moody does not suggest any weighting for the principles • The three first criteria are more fundamental than the other ones.	∨	+
[21]	• Introduction of an abstraction layer to business process models with depictive diagrams and natural language text to close the communication gap between modelling and domain experts.	-	+ 4.2 9.1
[22]	• Visual process representations may be superior to textual formats, but a badly constructed graphical representation may well be worse than a good textual representation.	-	+ 6.3
[23]	• Interactivity between model elements is positively related to cognitive difficulty.	-	9

[24]	• Discussion of chunks as foundation for the principle of Perceptual Discrimination. • Visual variables provide some interrelations for the variable color and brightness for pop-up.	∨	2.4
[25]	• Main concepts of modelling should be adopted by novice modelers step by step starting with simple visual modelling notations. • For better concept understanding more than one modelling notation should be mastered.	-	+ 9.1 9.2
[26]	• The idea of creating a marketplace of visual elements. This could make it possible to certify elements via empirical research. Additionally, the marketplace could offer insights into context-specific use of visual elements (e.g. for creating a dialect for a specialized domain)	-	+ 9.1
[27]	• Finding a balance between how 'satisfied' PoN principles are is a complicated task requiring information about what is more important. This can be achieved by eliciting requirements from users, seeing which are most often stated, and comparing them to the PoN's principles.	address the influences between PoN principles	
[28]	• Relevance of colors in different cultures to enhance the performance of visual communication via process models • We observe that color schemes that match cultural preferences can be applied mindfully to support visual communication. • culturally inappropriate modeling may lead to unnecessary additional cognitive effort on the model viewers	∨	+ 2.4 6.1

Based on this analysis the following concretions (highlighted in italic) result for PoN principles. A paper refines a PoN principle only if it directly addressed PoN and its operationalization (marked with ∨ and +) and confirmed its assumption with an empirical study. The following concretions were found, however, empirical studies are outstanding:

Table 5: Novel ideas for PoN but with outstanding empirical confirmation

PoN	Contribution
2.3	Use *well known and intuitive symbols known from other domains* to distinguish between them.
3.1	Use of icons to make diagrams more visually appealing. *Particularly, text labels combined with abstract graphical forms works best for novices.*
6.1	Use of color for redundant coding. *Culturally inappropriate modeling may lead to unnecessary additional cognitive effort on the model viewers.*

7.2	Textual encoding (e.g., *use cases*) can be used to reinforce and expand the meaning of graphical symbols.
8.2	Increase human discrimination by using *symbol sets without global notational deficiencies.*
9.1	Develop representations *by a large number of novices (crowdsourcing-based approach)* that are understood by both business and technical experts.

5 Evaluation of the Findings

To evaluate the value of our findings, we used the results from Table 4 to evaluate the visual notation of BPMN. We also related our findings to an evaluation of visual notations.

5.1 Application of the Findings to BPMN

The latest version of BPMN 2.0.2 provides visual notations for the diagram types Process, Choreography, Collaboration and Conversation (which is a specialized view of Collaboration) [29].

First, we evaluate **PoN 2.3**. This principle is related to the use of well-known and intuitive symbols from other domains. In BPMN 2.0.2 the symbols are conventional shapes and the symbol shapes were not designed with respect to understandability. Therefore, misinterpretations might arise. For instance, events assigned with a triangle define a signal. A triangle in the care industry, in contrast, express that any bleach is allowed with chlorine and oxygen [30]. A triangle in the German transport sector is associated with a danger event [31]. Other modeling languages set a better example such as the PICTURE method [32] or YAWL [33], which use, for instance, start and stop symbols of a player to define input and output conditions [34]. Definitely, some BPMN constructs evolve an appropriate association such as the timer event denoted by a circle and a clock. Overall, we agree with the evaluation of [34] and postulate to improve BPMN symbols according to **PoN 2.3**.

New insights to **PoN 3.1** empirically confirmed a preference for abstract graphical forms with text labels. BPMN allows specifying modeling elements as icons (e.g., task types, event types and activity marker) and to add text labels to these elements. Therefore, no specific recommendations can be given and the evaluation with respect to **PoN 3.1** remains the same as in [34].

An inappropriate color scheme increases cognitive effort according to new insights to **PoN 6.1**. BPMN is a black and white-notation. The colors of the modeling elements may be changed. The only restriction is that the markers for throwing events must have a dark fill [29]. Following new insights, then an appropriate context and culture-independent color schema should be used.

New insights to **PoN 7.2** recommend using use cases in order to reinforce and expand the meaning of graphical symbols. BPMN is the de facto standard for graphical process modeling domains and does not support written use cases as suggested in [35] and [36]. BPMN provides only the possibility to add annotations to modeling elements.

According to new insights to **PoN 7.2** it remains studying the extension of BPMN by written use cases.

According to **PoN 8.2** it is recommended to use symbol sets without global notational deficiencies. The following measures (see [34], [5]) for graphical visualization of BPMN elements are calculated:

- graphic complexity (=number of symbols) is 171,
- symbol deficit[2] is 23,6%,
- symbol excess[3] is 0,5%,
- symbol redundancy[4] is 0,5%, and
- symbol overload[5] is 5,4 %.

These measures point to weaknesses. However, these measures must be related with studies investigating the BPMN element usage as [37] and [38]. It has been shown that only a limited number of BPMN elements are selected. Empirical studies are necessary applying these measures to commonly selected BPMN elements and evaluating new insights of **PoN 8.2**.

Finally, an empirical support could be found for **PoN 9.1**. It is recommended to develop visual notations by a large number of novices (e.g. crowdsourcing-based approach). Such an approach has not been applied for BPMN. This insight to PoN 9.1 can be considered as complementary to PoN 2.3 and 8.2. To evaluate the frequently selected BPMN symbols a crowdsourcing-based approach can be a solution.

5.2 Relation of our Findings to prior Evaluations of Visual Notations

Our findings fuel the visual design of symbols. Exemplary, we point to the work of [39]. It has been argued that fewer constructs promote *Graphic Economy*. Such a statement can be found in the paper “Our survey shows that not only fewer *but symbol sets without global notational deficiencies should be used”*. This new insight should be considered in the future when pop-up effects of important constructs are investigated.

6 Conclusion and Outlook

The principles of the Physics of Notation (PoN) theory usually act as guidelines to evaluate and improve visual notations of process modeling languages. Due to the large number of empirical studies on business process models we were interested if new insights to PoN were also provided. Therefore, we performed a literature review in order to identify papers focusing on PoN or visual notations of process modeling languages in general. 14 related papers could be identified. A profound analysis of these

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[2] Describes the relative number of semantic constructs that are not represented by any graphical symbol.

[3] Describes graphical symbols, which have no correspond semantic construct.

[4] Means a semantic construct which represent by multiple symbols.

[5] Symbol overload is a single symbol which represent by multiple constructs.

works shows a confirmation of PoN and points to empirically studies confirming six operationalizations of PoN principles. The new insights to PoN principles were applied to an evaluation of the visual notation of BPMN 2.0.2. This evaluation revealed several weaknesses. Particularly, effort should be spent on the improvement of visual symbols of BPMN.

Even more research effort is necessary to confirm principles such as:

- **PoN 3.2** (**Semantically transparent relationships)**, which applies to representing relationships.
- **PoN 5.1 (Conceptual integration)** addressing mechanisms to help the reader assemble information from separate diagrams into a coherent representation of the system.
- **PoN 5.2 (Perceptual integration)** pointing to perceptual cues to simplify navigation and transitions between diagrams
- **PoN 8.2 (Introduce symbol deficit)**, which is related to the choice of not to show some constructs graphically.

Empirical studies on these PoN principles are essential in order to complete the understanding of influences on visual notations of process modeling languages.

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