The Impact of Perceived Cognitive Effectiveness on Perceived Usefulness of Visual Conceptual Modeling Languages

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Abstract. Users' perceptions and beliefs are relevant for the adoption of conceptual modeling languages in practice. This paper examines the relationship between user perception of the quality of a conceptual modeling language from a cognitive point of view and its perceived usefulness. The article builds on Moody's framework of quality characteristics of visual modeling languages. By means of an empirical study with 198 user ratings of diagrams drawn with different modeling languages used in the e-learning domain, we provide evidence that users' perception of criteria such as perceptual discriminability, graphic economy, a balanced combination of text and symbols, and semiotic clarity influence perceived usefulness of visual conceptual modeling languages. These findings and their implications for practice and research are discussed.

1 Introduction

Conceptual models are known to support the analysis, design, development, and documentation of software and data intensive systems. In particular, they are used for defining stakeholder requirements and for conceptualizing diffuse knowledge in a domain. Models document the stakeholders' understanding of a domain and the functionality of an information system. One main goal of requirements engineering is "conveying and promoting the understanding of the application domain" [1]. Consequently, models can improve the requirements engineering process and facilitate common understanding of domains and processes between users and system engineers [2]. Because of the positive effects, a large number of different modeling approaches targeting different levels or viewpoints within information systems—also addressing different domains—have been proposed. Yet, there is a discrepancy between (*a*) the attention paid to creating and developing modeling languages in research and (*b*) their actual usage by practitioners in real-world applications. For instance, in the e-learning domain, instructional designers find it difficult in practice to use visual modeling languages to describe their design artifacts due to their unfamiliarity and the intrinsic complexity of the languages used [3].

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The broad spectrum of available modeling languages makes beliefs and choices of users an important issue. Choice of modeling language is particularly relevant because "the world (reality) is never given to us in and of itself, but only through interpretation in some language" [4, p.148]. The perception of the (cognitive) effectiveness of a modeling language is likely to influence whether or not users perceive a language as useful and become interested in using the language. This is highly relevant in fields where there is no de-facto standard modeling language. Prior research showed that perceived ontological deficiencies in a modeling language negatively influence perceived usefulness and ease of use [5]. Other characteristics may have similar effects and influence the users' intentions to use a modeling language. For instance, research in several domains has shown that design aesthetics positively influence usage perceptions [6]. This paper follows up on this line of research. It goes beyond identifying and discussing cognitive effectiveness criteria of conceptual modeling languages, by connecting them to practitioners' usage beliefs. This approach differs from prior studies in that we investigate not only one, but a variety of criteria for cognitive effectiveness that users would be able to judge from a first impression of a language. Based on this we analyze which criteria are relevant for users' perception of the usefulness of the languages.

We use a theoretical framework on desirable cognitive characteristics of visual modeling languages [7] to assess the users' perceptions. Although there are already a number of frameworks available for evaluating modeling approaches, empirical research is still rare [1]. In previous research these frameworks were primarily used to conduct analytical expert evaluations of different modeling languages and analyze these in detail (e.g. [8,9,10,11]). We complement this thread of work by turning to the users' point of view and examine specifically how users' perception of quality characteristics relate to usage beliefs of conceptual modeling languages. In an empirical study 198 domain experts' ratings of different diagrams were collected. The ratings reflect the experts' judgment of three different visual modeling languages with regard to perceived cognitive characteristics and perceived usefulness. The data analysis demonstrates that these two dimensions are positively associated, which offers relevant input to understanding of the interaction between people and the conceptual modeling languages they use.

The rest of this paper is structured as follows. We begin with an overview of quality aspects in conceptual modeling. Then, we describe the research questions and the method employed in our empirical study. The next section presents our data analysis and an examination of the results. Finally, we present the implications of our research and discuss the limitations of our work.

2 Theoretical Background

2.1 Visual Modeling Languages

From a practical point of view, a conceptual modeling language is fundamental in order to allow a community to share their practices [12]. Using a visual modeling language—that is, a conceptual modeling language with a visual notation system—is the first step in narrating practices, and therefore to engage in reflective thinking as presented, for example, in Schön's *reflection on action* [13]. In the context of this paper we are interested in modeling languages that come with a visual notation. Such languages include "a set of graphical symbols, a set of compositional rules for how to form valid visual sentences, and definitions of their meanings" [7, p.756]. On the one hand, there are general-purpose visual modeling languages like the UML (Unified Modeling Language) [14] which can be used for modeling various perspectives on almost any kind of (information) system. On the other hand there are domain specific languages which are tailored for use by persons in a particular domain. A domain specific modeling language "directly represents the problem space by mapping modeling concepts to domain concepts" [15, p.19]. It matches vocabularies and mental representations of the domain experts and can therefore be a powerful and easy-to-use tool in a particular domain.

Visual models can support practitioners and their community to conceptualize problem spaces by providing a 'workbench' and toolkit for problem solving in exploring, creating, refining and redesigning design solutions. A shared, common language means that a community has a means to name and describe its environment and its inner dynamics, to identify problems, analyze them, and describe design solutions. As such, a shared language is the medium for the creation of a common ground [16], i.e. a shared understanding of a problem and of its possible solutions, and eventually of a shared culture in terms of the collection and construction of solutions and principles over time. Therefore, the language may improve communication, e.g. in design team meetings with fewer misunderstandings between experts and stakeholders due to the existence of a consistent terminology. It further enables designers and developers to generate and share design patterns by capturing the essential bits and pieces of a design solution to be adapted and reused for similar problems [17,18,19]. Last, but not least, by specifying requirements in specific settings, visual models may help to bridge the gap between design and implementation of a system. The provision of a detailed and unambiguous model can then be transformed into a working application.

2.2 Quality of Conceptual Models and Modeling Languages

Lindland et al. [20] proposed one of the first frameworks on the quality of conceptual models. It distinguishes three types of quality, namely syntactic quality, pragmatic quality and semantic quality. The framework is based on linguistics and considers four main elements: language, the modeling domain, the actual model, and the respective user. In this framework the *syntactic quality* refers to the consistency between the language and a model that was created by using the language. This consistency can be controlled via a comparison with the corresponding language grammar—that is, the modeling language's meta-model—and is therefore simple to assess. *Pragmatic quality*, however, describes a model's ability to help users in understanding the domain. In doing so, pragmatic quality connects the dimensions 'model' and 'user interpretation' of the model. Up to now, empirical studies often included the assessment of the user's perception (i.e. how easy/difficult it was to understand) and the usability (i.e. the perceived value, perceived ease of use, user satisfaction, and ease of use) [21]. *Semantic quality* captures the relationship between the domain and a model and determines how well a model conveys the intended meaning. Krogstie et al. [22] extended Lindland's framework with a fourth dimension: the *perceived semantic quality*. This dimension refers to the correspondence between the user interpretation (what a user thinks a model depicts) and the domain knowledge (what a user thinks a model should include). Semantic quality is difficult to measure, because it is hard to define what part of 'reality' is actually visualized in a specific model. There is a variety of studies comparing models against meta-models, or studies conducting ontological analyses to find out whether a grammar includes ontological deficiencies that may lead to scripts with low semantic quality [21].

Maes and Poels [21] additionally stress that a discussion of the quality of conceptual models from the users' point of view is relevant. By adapting measures stemming from popular information system success models to the area of conceptual modeling, they demonstrate that beliefs such as perceived ease of understanding and perceived semantic quality influence various attitudes such as perceived usefulness and, eventually, user satisfaction. Perceived usefulness is an important concept for measuring the users' overall quality evaluation of a modeling language. Since the actual objective of using a concepual model or a modeling language can have a variety of external influence factors, perceived usefulness is generally a robust success measure [21]. In the realm of conceptual modeling, we define perceived usefulness by replacing the term 'system' with 'conceptual model' in the original definition by Davis [23, p. 320]: "the degree to which a person believes that using a particular [conceptual model] would enhance his or her job performance".

There are several factors contributing to the quality of a modeling language. *Effectiveness* means how well a modeling language assists in accomplishing modeling goals, and *efficiency* refers to the resources needed to use a modeling language [1]. The users' interaction with modeling languages includes two main aspects, namely (*a*) the creation (authoring) of models, and (*b*) the understanding (assimilation) of models [1]. Not all modeling languages require the same effort (e.g. time, subjective ease-of-use) to learn to read and use the language. That is, models created with different modeling languages are likely to differ according to the effort required to interpret them and to develop an understanding. The form of visual information representation can have a significant impact on the efficiency of information search, the explicitness of information, and problem solving [24]. Moody [7] proposed 9 principles for high-quality design of visual languages from a cognitive viewpoint. These are semiotic clarity, graphic economy, perceptual discriminability, visual expressiveness, dual coding, semantic transparency, cognitive fit, complexity management and cognitive integration. Since one main interest in our study is to investigate users' perception of modeling languages, we will detail quality characteristics which users can perceive and judge also based on a first impression, i.e. without training on reading and using the language. Criteria like cognitive fit, complexity management, and cognitive integration are not further considered here, since users will only be able to judge these criteria after they develop interest in the language and become familiar with it to a certain degree. From Moody's criteria we therefore adopt the following for our study:

Perceptual Discriminability: Perceptual discriminability is defined as the "ease and accuracy with which graphical symbols can be differentiated from each other" [7].

Graphic Economy: A reasonable balance between the expressiveness of a language and the number of the symbols is demanded by the principle of graphic economy.

Dual Coding: A wise combination of text and graphical representation is referred to as dual coding, representing a further dimension for cognitively effective visual languages [7].

Visual Expressiveness: Visual languages which fully exploit the range of visual variables (e.g. spatial dimensions, shape, size, color, brightness, orientation, and texture) for their symbols offer a higher degree of visual expressiveness. If symbols differ according to several visual variables (e.g. color and size), they can be easily distinguished, and if a symbol has a unique value in the form of a visual variable, it is easily recognized.

Semantic Transparency: Semantic transparency describes whether symbols and their corresponding concepts are easily associated [7]. Similarly, McDougall [25, p. 489] refers to *semantic distance* to describe the continuum of "the closeness of the relationship between the symbol and what it is intended to represent". Icons, for example, are easily associated with their referent real-world concepts, because there is a direct relationship between them and their meaning.

Semiotic Clarity: Semiotic clarity refers to the importance of a one-to-one correspondence between selected concepts and their visual representation by a symbol. Anomalies such as symbol redundancy (more than one symbol representing the same concept), overload (one symbol representing more than one concept), symbol excess and deficit (when there are graphical symbols without a correspondence to a semantic construct, or vice versa) should be avoided, since they lead to ambiguity and additional unnecessary cognitive load for the user [7]. Research on the creation of domain-specific modeling languages reveals typical problems, e.g. that too many generic concepts for the domain or too many semantically overlapping concepts are chosen for a language; or that the language developer puts too much emphasis on specific concepts while neglecting other equally important concepts [26].

3 Research Questions

Having laid out the relevant theoretical background to examine cognitive effectiveness criteria related to the quality of visual modeling languages, we will now

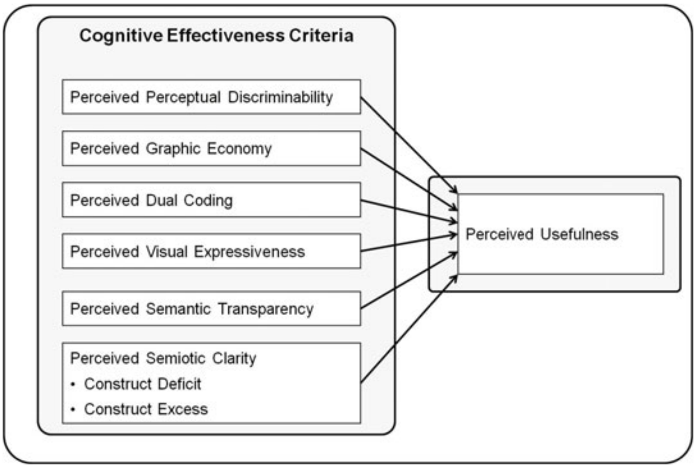

Fig. 1. Research model

explore how perceived usefulness varies depending on the perception of these quality characteristics. Hence, the main research question is: "How are users' perceptions of cognitive effectiveness criteria associated with their beliefs about the usefulness of the modeling language?"

The research model shown in Fig. 1 proposes that perceived usefulness is influenced by perceivable cognitive effectiveness criteria. The main proposition is that secondary quality criteria of a modeling language influence the formation of beliefs towards the language. This is backed up by previous research in conceptual modeling (e.g. [5]) and research on product perceptions (e.g. [6]). Prior research has found that there is a positive relationship between perceived usefulness and quality characteristics such as semiotic clarity of a language [5], perceived semantic quality and perceived ease of understanding [21]. Therefore, we expect a positive influence on perceived usefulness in case that users perceive symbols as highly discriminable, visually expressive and semantically transparent, graphic-economically chosen, and with appropriate use of the dual coding principle. Additionally, we hypothesize that perceived existence of construct deficit and excess would negatively affect perceived usefulness, since construct deficit is expected to limit expressiveness and modeling options.

4 Method

4.1 Design

To answer the research question and test the hypotheses we used a correlational study design. In a web-based questionnaire nine examples of diagram types from three different modeling languages were presented to users in random order. The users were asked to rate each diagram according to its cognitive effectiveness and its usefulness. They were instructed to rate the visual characteristics of the diagrams without paying specific attention to the actual content in the examples.

4.2 Materials

For the study, three modeling languages used in the e-learning domain for instructional design of learning processes and environments were selected as the object of evaluation. This specific domain was chosen because we had access to a large number of experts in that domain. Visual instructional design languages are important tools for e-learning design practitioners for several reasons related to the complexity of the domain [27]: for instance, instructional designers typically work in teams and therefore need a means of communication; for ensuring consistency between idea and implementation while retaining compliance with needs, goals and constraints; also, constraints and affordances of the available technologies need to be considered, which is becoming increasingly complex given the rate of technological innovation.

A visual instructional design language is defined as a set of concepts that support the structuring of the instructional design (i.e. specification) and/or the development (i.e. production) to support conceiving innovative solutions [28]. It is a conceptual tool for achieving more standardized and, at the same time, more creative design solutions, as well as enhancing communication and transparency in the design process. The main goal of a visual instructional design language is therefore the description of the "content and process within a 'unit of learning' from a pedagogical perspective in order to support reuse and interoperability" [29, p.10].

For this study we selected 9 diagram types defined in 3 different instructional design languages. As depicted in Fig. 2 we used diagram types from the following languages:

- *Educational Environment Modeling Language* (E^2ML) [30]: Goal Diagram, Dependencies Diagram, and Activity Flow Diagram;
- *Perspective-oriented Educational Modeling Language* (PoEML) [31]: Functional Goals Perspective Diagram, Participants' Perspective Diagram, and Order Perspective Diagram;
- *Cooperative UML* (coUML) [32]: Course Activity Diagram, Document Diagram, and Role Diagram.

4.3 Instrument

For most cognitive quality characteristics of modeling languages, there were no existing scales available. We therefore constructed two-item scales for each criterion in a way that they could be answered based on a single given diagram. The item construction was theoretically grounded on Moody's framework of desirable properties of visual languages [7]. The only exception was semiotic/ontological clarity, for which we could build on items previously developed by [5]. As mentioned in Section 2.2, knowledge of more diagram types and their relationships

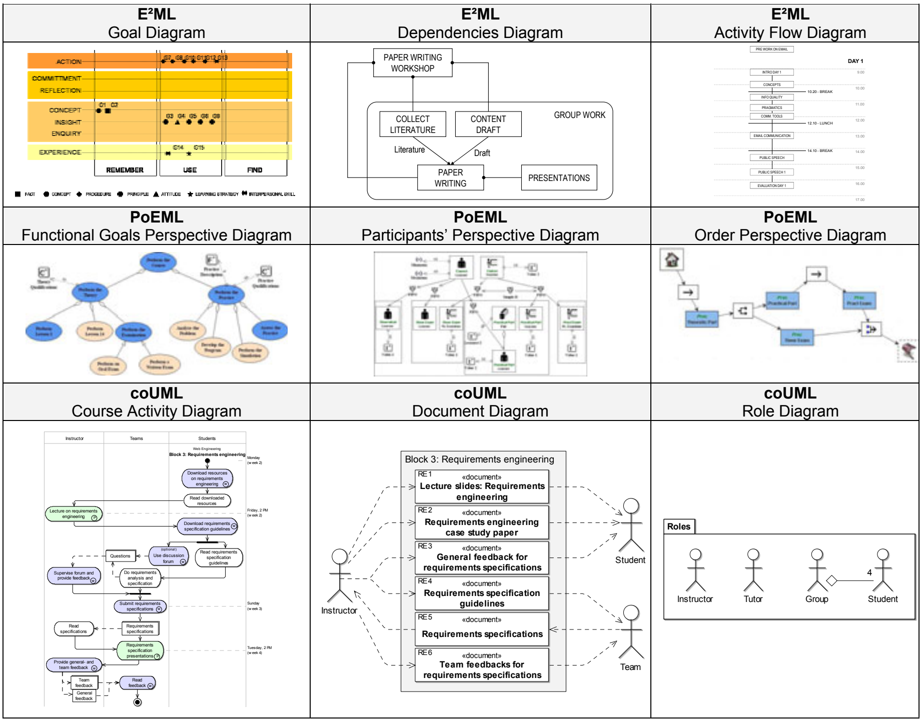

Fig. 2. Diagrams used in the user evaluation

would be necessary to evaluate the criteria of cognitive fit, complexity management and cognitive integration. Therefore, these criteria were not included in the questionnaire. To measure perceived usefulness of diagram types we adapted a scale proposed by [21] for the specific domain of the languages.

We ran a pre-test with 3 participants for ensuring content validity and for ensuring the understandable formulation of items before administering the questionnaire. Reliability analysis revealed adequate internal consistency for all scales (Cronbach's $\alpha > .8$), with the exception of visual expressiveness ($\alpha = .6$) and semiotic clarity ($\alpha = .2$). Cronbach's α should be greater than or equal to .7 to consider items to be uni-dimensional, therefore we analyzed single item scores instead of scale means for semiotic clarity. All items as well as detailed results of the reliability analysis can be found in the Appendix.

4.4 Sample

The final sample consisted of 198 user ratings of diagrams. Each of the 22 domain experts (12 males, 10 females), aged 34 years on average, had evaluated all 9 diagrams. Most participants were higher education teachers (13); the others were e-learning support staff at different universities (3) or researchers in the context of instructional design (6). Concerning experience with the domain, on

Table 1. Influence factors for perceived usefulness

Parameter	*Estimate*	*Std. Error*	*df*	*t*	*Sig.*	
Intercept	-.33	.60	73	-.54	.588	
Perceptual Discriminability	.18	.10	89	1.76	.082	+
Graphic Economy	.20	.11	67	1.87	.066	+
Dual Coding	.28	.10	85	2.93	.004	*
Visual Expressiveness	-.10	.12	92	-.84	.404	
Semantic Transparency	.15	.11	90	1.34	.182	
Semiotic Clarity: Absence of Construct Deficit	.21	.07	82	2.90	.005	*
Semiotic Clarity: Absence of Construct Excess	.06	.08	88	.74	.464	

$^{+} \ldots p < .1$ $\quad$ $^{*} \ldots p < .05$

average each participant had already been involved in the creation of 5 different instructional designs (e.g. courses or trainings).

5 Results

Hypotheses were tested using the linear mixed-effects models (MIXED) procedure in SPSS 19.0 with cognitive effectiveness criteria as independent variables and perceived usefulness as the dependent variable. The MIXED procedure can handle fixed and random effects. We included the variables 'domain expert' and 'diagram' as random factors in the model and assumed that each expert as well as each diagram would have a different intercept. The different experts had different intercepts ($Wald\,Z = 2.21, p = .027$), while the different diagrams did not have different intercepts ($Wald\,Z = 1.52, p = .128$).

Table 1 provides details of the analysis showing the parameter estimates of the fixed effects and significance levels. As expected, dual coding ($p = .004$) and absence of construct deficit ($p = .005$) had a significant positive effect. Additionally there was a trend that perceptual discriminability ($p = .082$) and graphic economy ($p = .066$) had a positive effect on perceived usefulness. The subjects' perceptions of semantic transparency, visual expressiveness and absence of construct excess did not have a statistically significant effect on perceived usefulness.

6 Discussion

The empirical study set out to investigate associations between users' perceptions of cognitive effectiveness of a modeling language and their beliefs about its usefulness. Results reveal that users' perception of criteria as perceptual discriminability, graphic economy, a balanced combination of text and symbols and absence of construct deficit are relevant influence factors for perceived usefulness of a visual modeling language. In line with our hypotheses, these results demonstrate that if users have the overall impression that a language is not well constructed, they will also tend to disregard its usefulness.

6.1 Limitations

Although the effects found in this study are evident and in line with previous research, there are some noteworthy limitations.

First, we acknowledge that the relationships between the variables could be examined in greater detail with artificially constructed test materials in which the criteria systematically vary. This could also shed more light on why criteria such as semantic transparency, visual expressiveness and construct excess were not relevant for perceived usefulness. One could argue that these are simply not as important. However, there may be other possible interpretations. Although we selected 9 different diagrams for the evaluation it could be that the diagrams did not vary enough for these criteria to be measured. Another explanation could be that these criteria were harder to judge for study participants.

Second, we recognize that further factors in the experimental materials (e.g. semantic quality of the diagrams) could have a deterring influence on the relationships that were investigated. However, in order to control for this possible threat to validity we had included nine different diagrams from different languages. In doing so, influences of external factors should be negligible. Nevertheless, future research could include even more diagrams and their evaluations to provide additional evidence.

Third, another limitation is that this study used a specific domain (instructional design) as a research object. Future research will have to take other domains into account to test the effects found in this study. Practitioners and modeling languages from other domains that have more (or less) tradition and affinity with visual modeling could be included.

Fourth, the selection of variables in the research model could further be extended and the influence or perception of quality characteristics on actual or intended use should be investigated in greater detail. Future research could examine additional variables—e.g. the perceived ease of use or actual use—to extend the research model we used.

6.2 Implications

The work presented in this paper carries implications for both research and practice.

For research streams investigating user attitudes and beliefs of conceptual modeling languages, our study adds to the current body of knowledge by investigating cognitive effectiveness criteria of modeling languages and their effect on perceived usefulness. Our results provide further indication into the importance of cognitive quality criteria of modeling languages as proposed by [7]. The results add to the growing body of analytical expert evaluations of modeling languages using this framework. Additionally, our work provides a first contribution on how to measure these quality criteria empirically through questionnaires.

From a practical viewpoint, the results reported here offer valuable suggestions for the design and construction of visual modeling languages. If adoption in practice is an objective (which it should be), efforts should not only be spent on the underlying basic concepts and constructs of the modeling language, but also on quality characteristics such as visual appearance and choice of symbols.

7 Conclusion

The study reported in this paper investigated the association of users' perception of quality criteria in visual modeling languages with their perceived usefulness. Based on Moody's criteria of cognitive effectiveness [7] we built a research model that enabled testing the effect of selected criteria on the perceived usefulness of visual modeling languages. The selection of criteria enables judgment of specific diagrams without requiring previous knowledge or expertise with the modeling language.

A set of 9 diagrams from 3 different visual instructional design languages was presented to study participants to judge. The results showed that four of the criteria included in the research model have a statistically significant positive influence on perceived usefulness. These are:

– Easy discrimination between different visual symbols (*perceptual discriminability*);
– Balance between high expressiveness and limited number of symbols (*graphic economy*);
– Balanced combination of textual and symbolic representations (*dual coding*);
– Absence of construct deficit, i.e. all relevant concepts are or can be represented in the modeling language (*semiotic clarity*).

These findings enable developers of visual modeling languages to propel the adoption by practitioners by considering the relevant criteria and thus improving the perceived usefulness of a language. This paper is intended as a contribution to raise awareness about and demonstrate the importance of cognitively effective design of visual conceptual modeling languages.

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Appendix: Questionnaire

- What is your age? (__ years)
- What is your gender? (Male/Female)
- What is your main role in the context of instructional design? (Instructor/E-learning support team of a university/Instructional design support of a university/Researcher in the context of instructional design)
- In the creation of how many different instructional designs (e.g. courses) have you already been involved? (__ instructional designs)

Instruction: "Please take a look at the following instructional design models and answer the questions based on these models! Details of the model content are less important as the models are only examples!"

The 9 different diagrams were shown as depicted in Fig. 2 followed by these questions:

- Dimension: **Perceptual Discriminability** (Cronbach's $\alpha = .956$)
  - There are symbols that are difficult to differentiate.
  - There are symbols that can easily be confused with each other.
- Dimension: **Graphic Economy** (Cronbach's $\alpha = .904$)
  - The diagram is difficult to understand due to the large number of symbols.
  - I think the amount of different symbols should be reduced.
- Dimension: **Dual Coding** (Cronbach's $\alpha = .846$)
  - The combination of text and symbols makes the diagram type easier to understand.
  - Textual annotations improve understanding of the diagram type.
- Dimension: **Visual Expressiveness** (Cronbach's $\alpha = .597$)
  - The visual expressiveness of the symbols should be increased by variation of color, size, form or brightness.
  - I perceive the symbols as visually expressive.
- Dimension: **Semantic Transparency** (Cronbach's $\alpha = .924$)
  - The symbols are intuitively understandable.
  - Even without explanation it is clear what the symbols represent.
- Dimension: **Semiotic Clarity** (adapted from [5]) (Cronbach's $\alpha = .223$)
  - Construct deficit - The diagram type could be made more complete by adding new symbols to represent relevant real-world phenomena of instructional design.
  - Construct excess - There are symbols that do not represent any relevant real-world phenomena of instructional design.
- Dimension: **Perceived Usefulness** (adapted from [21]) (Cronbach's $\alpha = .930$)
  - Overall, I think the diagram improves my performance when understanding the instructional design.
  - Overall, I found the diagram useful for understanding the instructional design.
  - Overall, I think the diagram would be an improvement to a textual description of the instructional design.