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Classifying instructional visualizations: A psychological approach

Abstract

Der Einsatz instruktionaler Visualisierungen hat sich durch die rasante Entwicklung der technischen Möglichkeiten in den letzten Jahrzehnten stark erhöht. Instruktionale Visualisierungen sind jedoch ein breites Konzept, das eine Reihe von Dimensionen umfasst. Visualisierungen unterscheiden sich nicht nur in ihren strukturellen Merkmalen (z. B. Dynamik, Interaktivität), sondern auch in ihren funktionalen Eigenschaften (z. B. Dekorations-, Repräsentations-, Organisationsfunktion). Diese beiden Dimensionen der Visualisierung wurden in der psychologischen Forschung besonders in Lernkontexten adressiert. Darüber hinaus wurde als dritte Dimension von Visualisierungen der dargestellte Inhalt identifiziert. Die große Vielfalt instruktionaler Visualisierungen schränkt die Generalisierbarkeit empirischer Forschungsergebnisse, die meist auf dem Einsatz spezieller instruktionaler Visualisierungen beruhen, ein. Deshalb besteht der Bedarf nach einem allgemeineren Klassifikationssystem, das es ermöglicht, bisherige Forschungsergebnisse zum Einsatz instruktionaler Visualisierungen zu strukturieren. Bisherige Klassifikationssysteme für Visualisierungen (z. B., Lohse et al. 1994; Rankin 1990) fokussieren entweder auf die strukturellen oder auf die funktionalen Dimensionen der Visualisierungen. Die vorliegende Arbeit gibt einen Überblick über die aktuelle psychologische Literatur zu den drei oben genannten Dimensionen mit dem Ziel der Entwicklung eines Klassifikationssystems, das die strukturellen, die funktionalen und die inhaltliche Dimension von Visualisierungen abdeckt. Das Ziel des Klassifikationssystems ist es, Visualisierungen unter Berücksichtigung aller drei Dimensionen zu Klassen ähnlicher Visualisierungen zuzuordnen. Das entwickelte Klassifikationssystem (in Form eines Fragebogens) wurde mit zehn Beurteilern an sechs verschiedenen zu klassifizierenden Visualisierungen evaluiert, um die Beurteilerübereinstimmung zu testen, um seine Praktikabilität während des Ausfüllens zu erproben und um seine Anwendbarkeit auf unterschiedliche Arten von Visualisierungen zu bewerten. Es zeigten sich hohe (bzw. beinahe hohe) Beurteilerübereinstimmungen für alle sechs getesteten Visualisierungen. Diese Ergebnisse weisen darauf hin, dass ein Klassifikationssystem in Form eines Fragebogens genutzt werden kann, um Visualisierungen objektiv zu klassifizieren.

The use of instructional visualizations has become very popular in the last decades, especially due to the rapid development of technical solutions. Visualization is a broad concept with diverse dimensions. Visualizations do not only vary with regard to their structural features (e.g., dynamism, interactivity), but they also have different functional features (e.g., decoration, representation, organization). Psychological research has investigated these two dimensions particularly in learning contexts. Moreover, a third dimension of visualizations, namely the depicted contents, has been identified. However, the high variability of visualizations is challenging with regard to generalizability of empirical research results found with a specific type of instructional visualization. Therefore, a generic classification system is needed to be able to structure the wide body of research. Although, some attempts to address the classification of visualizations have already been made (e.g., LOHSE et al. 1994; RANKIN 1990), those focus only on either structural or functional dimensions of visualizations. The current work reviews psychological literature on all three aforementioned dimensions aiming at developing a classification system covering the structural features, the functions, and the depicted contents. The classification system allows assigning visualizations to classes of similar visualizations with regard to all three identified dimensions. This classification system (in form of a questionnaire) was evaluated with ten subjects classifying six different visualizations in order to test the interrater reliability, to assess the usability during filling in the questionnaire, and to investigate its applicability to different types of visualizations. Data analyses revealed high, or close to high interrater reliabilities for all six visualizations. These results indicate that a questionnaire-based classification system can be used to objectively classify visualizations.

1. Classifying instructional visualizations: A psychological approach

The use of visualizations for depicting real life objects and relationships of objects has a long history. Given the technological development in the last decades, we are confronted with more and more visualizations in our everyday live. These visualizations range from simple black-and-white line drawings or paintings to highly realistic animations, photographs, films, or 3D-visualizations, to only name a few. Especially, in the context of education visualizations like diagrams, illustrated textbooks, educational films, and multimedia products play a stronger role today than a few decades ago. Despite the large use of visualizations in instructional contexts, it is from a psychological point of view still not clear, whether and when we benefit from visualizations or whether and when they are rather harming for learning. For instance, psychological research has shown that visualizations are not always beneficial for learning (e.g., LEVIN / ANGLIN / CARNEY 1987). Therefore, it is crucial to identify the conditions under which specific instructional visualizations are beneficial.

Research on the usefulness of visualizations often starts with an attempt to define visualizations and to distinguish them from other external representations (for an overview see e.g., RIEBER 1990; SCHEITER / WIEBE / HOLSANOVA 2008). We use the definition of Scheiter and colleagues, who characterized visualizations as a »specific form of external representations that are intended to communicate information by using a visuo-spatial layout of this information and that are processed in the visual sensory system« (SCHEITER ET AL. 2008, p. 3).

It has to be noted that visualizations usually do not occur in isolation. Rather they are mostly accompanied by text or are combined with other visualizations. Important psychological theories that deal with the combination of visualizations with other representations are the Cognitive Theory of Multimedia Learning (CTML, MAYER 2005), the Cognitive Load Theory (CLT, SWELLER / VAN MERRIËNBOER / PAAS 1998) or the Design-Functions-Task-Framework (DeFT, AINSWORTH 2006) for analyzing multiple external representations. These psychological theories have been used to analyze the effectiveness of visualizations in different learning scenarios. However, they pay only little attention to single representations, for instance to features of the visualization itself. Instead, they claim to provide general principles on the use of visualizations in the context of other representations. Particularly, in the psychological field of multimedia research, theories like the CTML (MAYER 2005) or the CLT (SWELLER ET AL. 1998) have elaborated several design principles for the beneficial use of visualizations in instructional settings (e.g., spatial and temporal contiguity of representations, modality principle). These design principles have been tested with only a very limited set of instructional visualizations, but are nevertheless generalized to the whole broad range of possible visualizations. Therefore, the unequivocal empirical results found in this research area can simply go back to the fact that very different visualizations are used in experimental studies. For instance, the contradictory results concerning the effectiveness of dynamic visualizations in comparison to static ones (e.g., HÖFFLER / LEUTNER 2007; TVERSKY / BAUER-MORRISON / BÉTRANCOURT 2002) show that general statements about the usefulness of different types of visualizations can hardly hold irrespective of the diversity of visualizations with regard to different dimensions. However, research findings concerning different visualizations are often lumped together into one single class (e.g., diagrams, photographs, and line drawings as examples of static visualizations) in order to derive general conclusions about this class of visualizations. However, this approach has not been very successful yet. For instance, it is difficult to decide whether dynamic visualizations are more effective than static ones when very different static visualizations are used for comparison. It might turn out, for instance, that dynamic visualizations outperform sequentially presented multiple static visualizations, whereas they may not be beneficial in comparison to simultaneously presented multiple static visualizations (IMHOF / SCHEITER / GERJETS 2009). Therefore, research on the instructional effects of different types of visualizations must be more specific with regard to characteristic features of the visualizations under consideration.

From a psychological point of view, deciding about the usefulness of visualizations in a certain learning context requires to consider and to investigate various aspects of visualizations in a systematic way. Therefore, a classification system for visualizations is needed to identify possible moderators for the effectiveness of visualizations. Such a classification system can be used to categorize visualizations into classes of similar and dissimilar visualizations in order to transfer important decisions about, for example, the usefulness of visualizations in given contexts from one visualization of the class to another. As different types of visualizations very likely require different competences to perceive, process, understand, and profit from them, a classification system will also be useful to address the role of individual characteristics and competences of viewers. For example, the viewers' ability to mentally rotate objects (e.g., HEGARTY / WALLER 2005) might not be important when learning with a 3D-Animation of the object, which can be rotated to inspect the object from different perspectives. The 3D-visualization might compensate for the viewers' inability to rotate the object in mind. However, having only access to a 2D-photograph of an object, the ability to mentally rotate may be crucial to acquire a correct mental model of the depicted object. Therefore, it does not seem to be useful to analyze the role of competences (e.g., the ability to mentally rotate objects) for learning from visualizations in general without taking the type of visualization used into account. Rather, those questions should be addressed for specific classes of visualizations. The current paper aims at providing a prerequisite for this type of research by proposing a classification system that incorporates dimensions of visualizations that are relevant from a psychological point of view because they affect the processing of visualizations.

Research has already identified several important aspects of visualizations, as the structural features or the functions of visualizations (e.g., LEVIN et al. 1987; LOHSE et al. 1994). Structural classifications (e.g., RANKIN 1990; BERTIN 1983) focus on the form of the visualization rather than its content. Functional classifications (e.g., MACDONALD-ROSS 1977; TUFTE 1983) focus on the intended use and purpose of graphic materials and do not reflect the structure of images (LOHSE et al. 1994). Unfortunately, in existing taxonomies only one of these aspects is regarded, whereas other dimensions of visualizations are disregarded or even ignored although it is important to consider all aspects of a single visualization in order to make statements about its usefulness. For instance, Lohse and colleagues (1994), although they theoretically introduced both, the structural as well as the functional dimension of visualizations, focus only on structural aspects in their own classification system. We assume that a successful classification system should integrate the two dimensions identified by Lohse and colleagues (1994) and that it even has to be extended by adding a third dimension, namely the content depicted in the visualization. Many instructional obstacles, approaches, or goals discussed in the psychological and educational literature are closely tied to content domains. Therefore, the content of visualizations is an important aspect that should not be left out.

2. Relevant aspects for the classification of visualizations

We propose a classification system for visualizations that is based on recent psychological literature and that comprises not only structural and functional features of visualizations, but also its contents. In order to provide a practicable and reliable classification system we chose a questionnaire format which allows researchers, developers, and users to characterize different aspects of visualizations that might contribute to their instructional effectiveness. The development of a classification system for visualizations is a first step in clarifying the question under what circumstances what kinds of visualizations are effective. We choose a broad approach, including relevant features of visualizations identified in current multimedia research as well as in other research fields, as for instance film and text comprehension, or research on television. In the following sections the relevant psychological literature on important dimensions of visualizations is outlined.

The classification system can be found in the Appendix. The dimensions and features addressed in the questionnaire are labeled with numbers and letters, which are used in the following sections for referencing (in parentheses).

2.1 Structural Features of Visualizations

Structural features are the most obvious features of visualizations. As structural features we define the dimension of visualizations that focuses on the form and the physical aspects (e.g., color, dynamism) of the visualizations and is objectively observable. This dimension is considered to be independent from the content or the functions of the visualization.

First, a visualization can be described by means of the relationship between the visualization as a representation and the object it stands for (Knowlton 1966). The semiotic code used by the elements of the visualization can be iconic, indexicalic, or symbolic (Peirce 1960: 1a). Iconic stands for the resemblance of a visualization to the depicted object in terms of its criterial attributes in a given context (e.g., a picture of a chair looks like a real chair), whereas indexicalic visualizations refer to the object by means of a causal physical connection to it (e.g., a footprint as a representation of a bear; Scheiter et al. 2008). In contrast, symbolic visualizations do not resemble the real object they are standing for and, thus, are arbitrary representations (e.g., electric circuit diagrams). The meaning of such symbols is defined through conventions (e.g., cultural conventions for graphical elements). The questionnaire additionally differentiates between known and unknown symbolic visualizations (1a), because it is possible that viewers do not have knowledge about the respective convention, so that the symbol is meaningless to them.

Second, the production technique of a visualization has to be classified in order to distinguish between, for example, photographs, film, computer graphics, drawing, painting, comic-strip, computer animation, or animated cartoon (1a). Different techniques for pre- and postproduction can be applied to each of those visualizations. For instance, techniques related to light, perspective, camera angles, shots and cuts play an important role in producing a film (Bordwell / Thompson 1993). However, the number of different pre- and post-production techniques is very large and thus would go far beyond the scope of the classification system to be developed (for a comprehensive description see Bordwell / Thompson 1993). We do not go into detail with regard to those techniques but simply focus for the purpose of this paper on some general techniques discussed in film research (e.g., Bordwell / Thompson 1993) that can be applied to static images as well. Accordingly, some broad features of the visualization with regard to light, camera angles, and shots have to be classified in the questionnaire (1b). Moreover, in the questionnaire the changes between pictures have to be characterized as changes between static visualizations, as camera movements, or as cuts (1c).

Third, another important structural feature of visualizations is the degree of dynamism (1d). Although an overall advantage of dynamic visualizations over static visualizations in the context of learning could be found (Höffler / Leutner 2007), there are many gradings within these two extremes. Static visualizations can be depicted as a single static picture or as multiple static pictures, whereby the multiple static pictures can be depicted simultaneously all together on one page or sequentially one after another (Imhof et al. 2009). Dynamic visualizations can be depicted segmented or continuously (Mayer / Chandler 2001) or several dynamic visualizations can be depicted at once (Rebetez / Bétrancourt 2008). Moreover, static and dynamic presentation formats can be mixed in one visualization (Rebetez / Bétrancourt 2008). Another important aspect of dynamic visualizations is their complexity (Lowe 1999: 1d). Several objects, moving at the same time, increase the complexity of visualizations. Furthermore, it is important whether the duration of the presentation is determined or not (1d). This aspect is closely related to the interactivity of the visualization.

Fourth, visualizations can entail different forms of interactivity (1e). Schulmeister (2003) identified six different levels of interactivity in his taxonomy for multimedia components. The first level contains only watching visualizations without any possibility to influence them. The second level allows changing the visualization by clicking on it, selecting options, menu items, or hypertext links. At level three, varying the form of the representation becomes possible. Level four includes the manipulation of the content of the visualization by creating new visualizations through newly entered data or variation of given parameters. Constructing a new visualization is a characteristic of level five. Finally, constructing a new visualization and receiving intelligent feedback from the system through manipulative action indicates level six. Mayer and Chandler (2001) showed that minimal amount of interactivity can already lead to better learning outcomes. Moreover, interactivity can enhance the motivation in learning scenarios (e. g., Levin et al. 1987; Lowe 2004). We included four aspects of interactivity into the classification system (1e): basic interactivity, influence on the depiction, influence on sequencing (non-linearity), and options for manipulation.

Fifth, visualizations are often accompanied by text (written or spoken; Mayer 2005; Sweller et al. 1998: 1f), additional audio (e. g., film music; 1g) or noises (e. g., telephone ringing; 1g). There is a substantial body of research on the combination of visualizations and text. In order to remain within the scope of this article, we will not go into detail with regard to this topic, because we are mostly concerned with the visualization itself as a single representation. For further reading, research within the framework of CLT (Sweller et al. 1998) and CTML (Mayer 2005) should be consulted. In the questionnaire the text modality, text type, and the language (1f) as well as the type of music and noises (1g) have to be indicated.

Sixth, the amount of realistic details depicted differs along several visualizations (e. g., Dwyer 1976; Höffler / Leutner 2007; Rothmund / Schreier / Groeben 2001; Scheiter et al. 2009: 1h). Realism is the similarity of the represented object to the visualization (Rieber 1994). This similarity is achieved by imitating the real-world referent with respect to color, shape/contours, textures, or spatial relationships (for an overview see Scheiter et al. 2009). Moreover, the presentation speed of the dynamic visualizations (Fischer / Lowe / Schwan 2008) and the voices and noises used can be more or less realistically (1h).

Seventh, visualizations can be provided with additional cues like arrows or highlights (cf. De Koning / Tabbers / Rikers / Paas 2007: 1i). Cues in visualizations are additions of non-content information that have the function of guiding attention to important aspects of the visualization (De Koning et al. 2007). Though cues have a functional component, they are also structural features of visualizations.

2.2 Functions of Visualizations

Visualizations do not only comprise structural features. They also have intended functions, which are described in the following section. There are several approaches to classify the functions of visualizations.

First, visualizations have affective functions as they can influence the motivation, the emotions and moods, and the attitude of viewers (Levie / Lentz 1982; Lowe 2004: 2a).

Second, Levie and Lentz (1982) also found attention guiding functions such as attracting or directing attention. Additionally, Anderson and Kirkorian (2006) identified a third function of visualizations in terms of attention, namely maintaining the attraction of viewers (2b).

Third, visualizations have supplementing functions when they accompany other representations, either text or visualization. Levin and colleagues (1987) found five text-supplementation-functions (2c). The decoration function is associated with text-irrelevant pictures that make a textbook look more attractive or motivating, what is also an affective function. The representation function occurs if actors, objects, and activities taking place in narrative passages are represented in the picture. Those visualizations ›tell‹ exactly the same story as the text. Visualizations that make a text content more coherent can be either organizational or interpretational. Organizational visualizations provide an organizational framework for a text (e. g., maps), giving it greater coherence, whereas interpretational visualizations clarify difficult-to-understand passages and abstract concepts within passages (e. g., advanced organizers). Whereas a text associated with organizational pictures is easy-to-process (because it focuses on simple or familiar concepts described in a straightforward fashion), a text associated with interpretational pictures describes more unfamiliar, difficult, concepts (e. g., technical terms and their associated characteristics). Moreover, visualizations may offer a transformation function: transformational visualizations are meant to influence viewers' memory directly by transforming critical information into a more concrete and memorable form.

However, visualizations are not only used as text adjuncts. They may also accompany other visualizations. This is addressed within the DeFT fraimwork (Ainsworth 2006). Besides the design of the visualizations (De) this approach addresses the three key functions (F) of multiple external representations for cognitive tasks (T): complement, constrain, and construct (2c). Visualizations accompanied by other visualizations or by text can complement each other, because they differ either with regard to the processes (e. g., computational off-loading, procedural fit; cf. Scaife / Rogers 1996: 2d) they support in working memory or in the information they contain. One visualization can also be constrained by another visualization or by text. For example, graphics are more specific than texts: the sentence ›it is raining‹ does not provide any information about the amount or the size of the raindrops, whereas a picture on which it is raining automatically specifies these aspects of the rain. The constructing function leads to a deeper understanding, when information of multiple external representations is integrated and increases the likelihood for transfer to new situations.

Fourth, Levie and Lentz (1982) found long-term memory supporting functions that visualizations have as text illustrations: they can facilitate the remembering and understanding of text contents and they can provide additional information thereby deepening the understanding of the text (2e).

In the classification system, five different functions of visualizations have to be classified, namely the affective functions (2a), the attention-guiding functions (2b), the (text-/picture-) supplementation functions (2c), the working memory supporting functions (2d), and the long-term memory supporting functions (2e). There is the additional option ›unclear‹ for each of the five functions, because without knowing the intentions of the developers and the context of usage it might be hard to define the functions of some visualizations correctly.

2.3 Content of Visualizations

Besides structural and functional features, visualizations also have a certain content that can be described with regard to its genre, target audience and other aspects. In the following section the content relevant aspects of visualizations are described. The depicted content can vary with regard to its intention, which can be, for instance, didactic as in most multimedia learning environments, journalistic as in newspapers, or entertaining as in films (3a). The genre used to present the contents can either be expository, narrative, or procedural (McCarthy et al. 2009: 3a). Expository content presentations have the purpose to inform, explain, describe, define or depict the reality directly (Lock / Lockhart 1998), whereas narrative content presentations convey fictional or non-fictional events (e.g., Bordwell / Thompson 1993). Procedural contents address skills and procedures, or the ›know-how‹ knowledge, as for instance in instructions. All possible combinations of expository, narrative, and procedural could be chosen in the questionnaire as mixtures (3a). For instance, an instructional visualization can start with a narration as example followed by expository explanations. In addition, there are visualizations that do not depict contents in an expository, narrative, or procedural form but that present visual art or poetry (3a).

Second, the content of visualizations itself can be depicted more or less realistically (3b). This aspect has to be distinguished from the degree of realism used by the depiction itself (see above). Rothmund et al. (2001) differentiate between those two types of realism and assume that viewers evaluate the depicted content against their own knowledge about the reality. The distinction between realistic and fictional contents is not a binary one; rather, it is a continuum with realistic contents forming one end of the dimension and fictional contents forming the other. Furthermore, the content of visualizations can be evaluated with regard to a second continuum ranging from staged to documentary. In the questionnaire, the realism of the content has to be classified with regard to persons, objects, situations, events, and the plot (Rothmund et al. 2001).

Third, the presence of persons or objects within a visualization leads to another important aspect of the content, namely the identification object and the degree of identification (3c). It is important whether and to what degree the viewer identifies him-/herself with depicted persons or objects.

Fourth, as identified in text comprehension research, coherence is a central concept influencing the processing and the understanding of representations (e. g., Zwaan / Singer 2003: 3d). Magliano, Miller, and Zwaan (2001) investigated coherence in films, especially the temporal and the spatial coherence, which plays a crucial role for understanding filmic contents. Besides of the temporal and spatial coherence three other types of coherence have to be classified in the questionnaire: visual coherence, coherence with regard to the content, and the coherence between representations.

Fifth, the complexity of the inferences necessary to overcome coherence breaks has to be rated (3). Sixth, the detailedness of the depiction in comparison to the complexity of the contents has to be rated (3f). Seventh, an important aspect of the content is the domain (e.g., science, sports, art, propaganda, etc.; 3g). As identified in the meta-analysis of Höffler and Leutner (2007) different visualizations are suited for different domains. Eighth, whenever the content is described, it is important to consider the aspired target group with regard to its age, gender, expertise level, and possible special interests (3h).

2.4 General Comments on the Classification System

The proposed classification system (see Appendix) is designed as a questionnaire with predefined answers and three main parts covering the three dimensions structural features, functions, and content of visualizations (seven pages in total). Each visualization has to be rated separately. For the items within the questionnaire two different ways to provide predefined answers are implemented: radio buttons provide the opportunities to choose one out of several possible answers, whereas check boxes allow to choose answers without that restriction. Moreover, some items are divided into sub-items, which are separated from each other with dashed lines, indicating that in each separated section at least one answer is required. In addition, some items use a free response format, for instance, the title, author, year of production, presentation mode, and the short summary of the visualization. These general items have to be answered at the beginning of the questionnaire. Most questions allow for choosing a ›miscellaneous‹ alternative, because the current classification system does not claim to provide a list of exhaustive alternatives.

3. Evaluation of the classification system

The usability of the proposed questionnaire was tested with ten independent raters, who rated six different visualizations. The visualizations comprised a computer animation about cancer (http://tumorzentrum.klinikum.uni-muenster.de/aerzte/mammakarzinom/doenneb/index.htm), an impressionistic painting (CLAUDE MONET: The stroll, 1875, National Gallery of Art, Washington), a static text-picture combination (adapted from WORT & BILD VERLAG, 2006), an animated cartoon (BARILLÉ 1986), a section from a silent film (CHAPLIN 1921), and a section from a television movie (BEIMLER et al. 1989). To test the interrater reliability for all possible 45 pairwise comparisons between the ten raters Cramérs V was calculated for each of the six visualizations. The range for Cramérs V is between 0 and 1 and values larger than 0.6 are referred to as high interrater reliabilities (WIRTZ / CASPAR 2002). Table 1 shows the results for the six test visualizations.

Four of the six tested visualizations, namely the computer animation, the painting, the silent film, and the movie, reached high interrater reliabilities for the ten independent raters. The remaining two visualizations, namely the static text-picture combination and the animated cartoon, reached a close to high interrater reliability.

Table 1: Interrater reliabilities.

Visualization	*Cramérs V*
Computer animation	*V = .74*
Painting	*V = .83*
Static text-picture-combination	*V = .57*
Animated cartoon	*V = .57*
Silent film	*V = .80*
Television movie	*V = .79*

4. Discussion

The purpose of this paper was to present a feasible classification system in form of a questionnaire that allows to classify a broad range of visualizations according to different dimensions. This classification system may be useful for future research to identify situational constraints, individual learner prerequisites, and instructional contexts related to an effective use of different types of instructional visualizations.

A first evaluation of the developed classification system revealed a high or almost high interrater reliability for six different test visualizations. Interestingly, the two visualizations that achieved only a medium interrater reliability were rather schematic with regard to their degree of realism compared to the four visualizations with high interrater reliability, which were all depicted rather realistically. This result indicates that schematic visualizations might be seen more diverse than realistic ones. This effect can go to the fact that realistic visualizations are more similar to our everyday experience that provides a common ground for the interaction with our peers. In contrast, schematic visualizations are only encountered in specific situations (e. g., learning contexts) and thus, their familiarity and, consequently, their assignment to classes might differ more among different expertise levels. Moreover, the two visualizations with medium interrater reliability differed from the other visualizations also with regard to the following features: the static text-picture combination was the only test visualization that (a) was combined with written text, that (b) consisted of multiple static pictures, and that (c) conveyed procedural instructions. The animated cartoon was different from the other visualizations in that it was (a) longer than the other ones and entailed (b) more different sections than the other dynamic visualizations. A longer, respectively information-richer visualization might promote more possibilities for misinterpretations. This might lead to different classifications. To identify specific difficulties in classifying certain types of visualizations further research is needed. In particular, the interrater reliabilities for the three dimensions of the classification system and the individual items should be investigated separately to identify problematic items. For instance, it is probably easier to identify a visual arrow as a cue than to identify long-term memory supporting functions of visualizations.

Previous classification approaches as well as this classification system do rely to a large extend on the scientific intuitions of their authors. Therefore, more substantial empirical work is needed to indicate which of the numerous dimensions of visualizations should be primarily used for a classification of instructional visualizations. A more thorough evaluation of the proposed classification system with more test visualizations and different types of raters would be a first desirable step. A larger data set for different visualization types would allow for more sophisticated statistical analyses like cluster and factor analyses that can inform a standardization of the classification system and its items.

Eventually, the classification system may be a helpful step towards identifying individual learner competences and beneficial circumstances that are important for the effectiveness of different types of visualizations. It might also help to shed some light on inconsistent results concerning the effectiveness of instructional visualizations. In particular, a meta-analysis using this type of classification to review previous research on visualization effects might substantially contribute to future research on instructional visualizations.

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Appendix: Classification of visualizations

Title: ______________________________

Author: ______________________________

Year of production: ____________ Presentation medium: __________________

Summary: ______________________________

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1. Structural features			
1a) Visualization	**Production technique:**		
	O photograph	O film	O computer graphics
	O drawing	O painting	O computer animation
	O comic strip	O animated cartoon	O miscellaneous
	Visualization type:		
		O iconic	O symbolic known
		O indexicalic	O symbolic unknown

1b) Techniques used for pre- and post-production	**Light:** ☐ shaded ☐ normal ☐ brightened ☐ natural ☐ artificial ☐ undefined ☐ hard ☐ normal ☐ soft ☐ frontal light ☐ backlight ☐ sidelight ☐ overhead light ☐ lower light ☐ undefined source **Camera angles:** ☐ bottom-shot ☐ worm's-eye view ☐ low angle shot ☐ normal view ☐ high angle shot ☐ bird's-eye view ☐ top-shot ☐ tilted camera (dutch angle) **Shots:** ☐ long ☐ wide ☐ full ☐ three quarter ☐ medium ☐ head & shoulder ☐ close-up ☐ extrem close up

1c) Changes between pictures O yes O no	☐ **Between static visualizations** ☐ **Camera movements** O horizontal O vertical O both .... O slow O fast O whip pan .... ☐ accompanying ☐ panorama shot ☐ **Cuts** ☐ direct cut ☐ gradual changes O fading O dissolving O wipe length of the sequence: O long O getting longer O mixed O short O getting shorter
1d) Dynamism	**Degree of Dynamism:** O single static O static-simultaneous O static-sequential O dyn. segmented O dynamic continuous O multiple dynamic O static-dynamic mixtures O miscellaneos ☐ **Complexity** (concurrent movements of several objects): O high O unobtrusive O low **Duration of the presentation:** O determined: ________________ O not determined

1e) Interactivity O yes O no	☐ **Basic interactivity:** ☐ start ☐ stop ☐ forward ☐ rewind ☐ sound volume ☐ **Influence on the depiction:** ☐ zoom ☐ presentation speed ☐ changes in the perspective ☐ **Influence on sequencing (non-linearity):** ☐ **Options for manipulation:** ☐ dyna-linking ☐ simulations ☐ drag-and-drop ☐ feedback
1f) Text O yes O no	**Modality:** ☐ visual ☐ auditory ☐ haptic **Text type:** ☐ label ☐ subtitle ☐ underline ☐ heading ☐ caption ☐ continuous text/dialog ☐ miscellaneous **Language:** O native O foreign O multilingual

1g) Additional audio O yes O no	☐ **Music:** ☐ situational ☐ added (film music) ☐ instrumental ☐ vocal ☐ **Noises:** ☐ situational ☐ added
1h) Realism of the depiction	**Color:** O realistic O understated O different O exaggerated **Shape/ Contours:** O realistic O understated O different O exaggerated **Textures:** O realistic O understated O different O exaggerated **Spatial relationships:** O realistic O understated O different O exaggerated ☐ **Presentation speed:** O real time O slower O faster ☐ **Voices:** O realistic O understated O different O exaggerated ☐ **Noises:** O realistic O understated O different O exaggerated

1i) Cues O yes O no	☐ auditory ☐ visual ☐ colored ☐ moving

2. Functions	
2a) Affective functions O yes O no O unclear	**Influence on:** ☐ motivation ☐ emotions/ mood ☐ attitude
2b) Attention-guiding functions O yes O no O unclear	☐ attracting ☐ adapting ☐ maintaining
2c) (Text-/picture-) supplementation functions O yes O no O unclear	☐ decorational ☐ representational ☐ organisational ☐ interpretational ☐ transformational .... O redundant O complementary O contrary ☐ constraining
2d) Working memory supporting funct O yes O no O unclear	☐ off-loading (e.g., graph vs. table) ☐ procedural fit (e.g., roman vs. arabic numerals)

2e) Long-term memory supporting functions O yes O no O unclear	☐ facilitation of remembering ☐ facilitation of understanding / application ☐ deepening of understanding (abstraction)

3. Content	
3a)	**Intention**
Genre	☐ scientific ☐ didactic ☐ journalistic
	☐ entertaining ☐ appealing ☐ miscellaneous
	☐ **expository (E)**
	☐ description ☐ recommendation ☐ discussion
	☐ analysis ☐ argumentation
	☐ **narrative (N)**
	O Narrator: ☐ first-person ☐ third-person
	☐ omniscient ☐ monologe
	☐ dialogue
	☐ subjective sound ☐ subjective camera
	☐ inner images
	☐ **procedural (P)** O instructions O normative rules
	☐ **Mixtures** O EN O EP O NP
	O NE O PE O PN
	☐ **Visual art (»visual poetry«):**
	O traditional art
	O media art
	O documentation (e. g., filmed performances)
	O self-contained media art (e. g., video sculptures)

3b) Realism degree of the content	☐ **Person / Object:**	☐ realistic ☐ staged	☐ fictional ☐ documentary
	☐ **Situation:**	☐ realistic ☐ staged	☐ fictional ☐ documentary
	☐ **Event:**	☐ realistic ☐ staged	☐ fictional ☐ documentary
	☐ **Plot:**	☐ realistic ☐ staged	☐ fictional ☐ documentary
3c) Identification O yes O no	**Identification object:** O one **Degree:**	O several O low	O changing O high

3d) Coherence /Continuity	**spatial:**	O exaggerated	O unobtrusive
		O inferences (local and/or global)	
		O coherence breaks	
	visual:	O exaggerated	O unobtrusive
		O inferences (local and/or global)	
		O coherence breaks	
	content:	O exaggerated	O unobtrusive
		O inferences (local and/or global)	
		O coherence breaks	
	☐ **temporal:**	O exaggerated	O unobtrusive
		O inferences (local and/or global)	
		O coherence breaks	
	☐ **between representations:**		
		O exaggerated	O unobtrusive
		O inferences (local and/or global)	
		O coherence breaks	
3e) Complexity of neces- sary inferences	O high	O low (unobtrusive)	

3f) Detailedness of the presentation in comparison to the complexity of the contents	O short/concise	O adequate	O extensive
	O simplifying	O adequate	O complicating
3g) Domain	O natural sciences		O sports
	O humanities		O art/culture
	O politics/society		O »entertainment«
	O advertisement/propaganda		O miscellaneous
	O »cultural techniques« (e. g. reading, writing, calculating, cooking, knot tying, …)		
3h) Aspired target audience	**Age:**		
	O children	O adolescents	O adults
	O elderly	O mixed	
	Expertise:		
	O experts	O novices	unspecified O
	☐ **Special interest group**		