Chapter 1
What Is an Effective Knowledge Visualization? Insights from a Review of Seminal Concepts

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Abstract The domain of knowledge visualization (KV) focuses on the collaborative use of interactive graphics to create, integrate, and apply knowledge. This emerging approach nevertheless builds on decades of research on using images collaboratively for sense making and knowledge sharing. In this chapter, we review the seminal concepts from different disciplines that help to explain how visualizations can effectively act as collaboration catalysts and knowledge integrators. Our review makes it apparent that many different labels and conceptions exist in very different domains to explain the same phenomenon: the integrative power of visuals for knowledge-intensive collaboration processes. These concepts can be used to compile a list of the requirements of an effective KV. We conclude this chapter by showing the theoretical and practical implications of this review.

1.1 Introduction

The domain of knowledge visualization (KV) is a relatively young discipline that focuses on the collaborative use of interactive graphics to create, integrate and apply knowledge—particularly in the management context. This young field nevertheless builds on decades of research on using images collaboratively for sense making and knowledge sharing.

The objective of the current chapter is to make this rich legacy of the knowledge domain field visible and use it to inform the practice of visualizing knowledge. In this chapter, we will thus review the seminal concepts from different disciplines that help to explain how visualizations can act as collaboration catalysts and support the elicitation, integration, and application of knowledge on a team or group level. This review will make it apparent that many different labels exist in various domains to explain the basically same phenomenon: the integrative power of visuals for knowledge-intensive collaboration. Our review of the key concepts, however, will also reveal that visuals must meet certain criteria to achieve this integration function effectively.

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This chapter is structured in the following manner: First, we provide an example of a KV and discuss the already-identified attributes of such epistemic (knowledge-intensive) images in Sect. 1.2. Then, we describe the rationale behind our review of the key concepts that can inform KV conceptions in Sect. 1.3, where we also discuss seminal, highly cited constructs from disciplines as diverse as sociology, art history, e-learning, psychology, epistemology, or design. We cluster these constructs according to their emphasis on visualization or collaboration respectively. As a main contribution we identify similarities among the concepts and summarize them in five derived KV principles. To illustrate these principles, we focus on a few seminal concepts in more depth in Sect. 1.4. In the subsequent Sect. 1.5, we derive implications from the reviewed constructs for the theory and practice of KV. The final Sect. 1.6 of this chapter consists of a short conclusion and an outlook on future research in this area.

1.2 The Realm of Knowledge Visualization

We define KV (in contrast to the mostly data-driven information visualization field) as follows: KV designates all (interactive) graphic means that can be used to develop or convey insights, experiences, methods, or skills [6, 7]. This definition implies that the realm of KV is not limited to computer-based images and that the main purpose of KV is to support the (inherently social) processes of creating and sharing knowledge with others.

Figure 1.1 provides a simple example of this approach. This figure represents the completed analysis conducted by a management team regarding the service quality problems in their call center. Starting with the empty iceberg metaphor (as a discussion template) and its tip containing the label "service quality low", the team went to probe its root causes and mapped the main issues or problem drivers in a reverse causal chain backwards to the less visible problems (in the lower part of the iceberg). In doing so, the group elicited the team members' different insights regarding the current challenges in the call center. The graphic iceberg template and corresponding facilitation method enabled the team to pool these insights and relate them to each other, as well as devise adequate improvement actions.

The resulting image can then be used in subsequent meetings to explain the problem to other staff members and to help in the implementation of improvement measures. The image contains knowledge on a detail level, such as the impact of budget restrictions on the available infrastructure, as well as one overall insight, namely that the service quality level is just the tip of the iceberg of a much larger problem. The image in Fig. 1.1 is a typical knowledge representation in the sense that it contains various types of images, such as the visual metaphor of an iceberg, sketch marks for highlighting (the blue circle) as well as diagrammatic elements (text elements and arrows). It also indicates a process of how to discuss the problem analysis, namely in an overview to detail, top-to-bottom process.

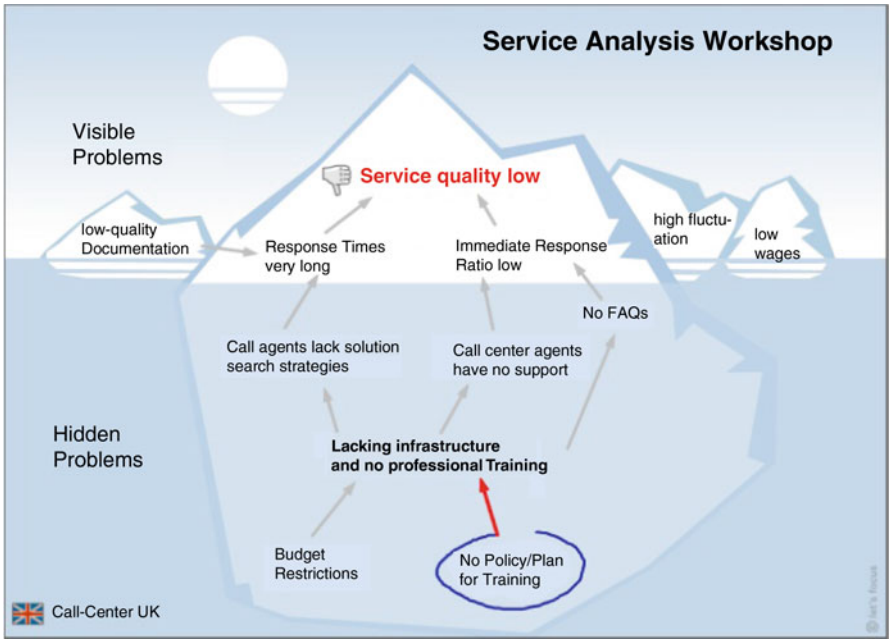

Fig. 1.1 An example of a knowledge visualization

A KV, such as the simple one depicted above, consequently has to fulfill the following criteria to merit the label in our (group-level) application context:

1. It has to be able to *capture* and *depict Knowledge*, that is to say (valid and current) insights, experiences, concepts, perspectives, opinions arguments, etc., of informed participants.
2. Ideally, it contains *insights* from more than one *person* alone and *relates* these ideas to one another.
3. It has to be *visual* in the sense that the knowledge mapped in the image is spatially positioned within a diagram, visual metaphor (as above), sketch, map, or photograph, or combinations thereof.
4. It has to support the (group) *process* of knowledge integration among various people. It should in other words *facilitate (synchronous or asynchronous) conversations*.
5. To achieve this, the visualization has to be *revisable* or flexible, so as to be able to react to changing insights in a group over the course of time.
6. It has to be *communicable* in the sense that the image can be communicated to others (of different professional background) who have not been present during its creation process (this is, for example, a common problem with the use of mind maps).
7. Ideally, its use leads to *new discoveries* or insights that were previously unknown and that are *useful* to viewers of the visualization.

These criteria are derived from the cognitive [9] and collaborative dimensions of visualization research [1] and from the practical use of KVs in management [6, 7]. However, requirements for KV may go beyond this straight forward list of attributes. Are there other key characteristics that KVs should exhibit to support knowledge processes? Are these seven attributes confirmed by approaches in other domains?

To answer these questions, we have reviewed seminal concepts related to 'collaboration through artifacts' (the larger subject domain). These concepts are shortly presented and compared in the next section.

1.3 A Review of Seminal Concepts

Having described the goal and rationale of reviewing concepts related to KV and more broadly working with artifacts to share knowledge, we now proceed to a concise overview of closely related constructs from different domains.

Altogether, we have been able to identify the following concepts that describe the key notion of using visualization as a catalyst for knowledge sharing. Each one contains a profound insight into the nature of images as collaboration platforms. We will briefly discuss these insights in this section.

The selection criteria for these concepts were that (a) they have to be highly cited, i.e., have achieved more than at least 100 citations (in Google Scholar), (b) they have to specifically address (at least partly) images as knowledge exchange mechanisms, and (c) relate them to collaboration contexts (to a lesser or greater extent).

We were also interested in concepts from radically different domains, so that different kinds of insights into collaborative visualization could be fruitfully integrated.

To select highly influential concepts, we have counted the total amount of citations reported on Google Scholar for the first three articles (in terms of citations), employing the concept in the article title or abstract. This has lead to the list of seminal concepts that appears in Table 1.1.

These concepts not only differ with regard to their disciplinary background, but also with regard to their respective focus. As we have shown in Fig. 1.2, the concepts can be distinguished regarding their emphasis on the role of images or on the actual collaboration that (graphic) artifacts can support.

The resulting segmentation shows two main groups of concepts, namely those focusing on visualization (represented by visualization scholars such as Edward Tufte, James Elkins, or Barbara Tversky), and those focusing primarily on collaboration (visualized as empty bubbles in the matrix, such as the ethnographic work of Barbara Knorr-Cetina in the context of scientific discovery, or of Kathryn Henderson in the area of design engineering).

More important than their differences, however, at times, are the astonishing (given their radically different backgrounds) similarities among these concepts. In Table 1.2, we have articulated the key requirements for KV directly deduced from these seminal concepts.

Table 1.1 The key concepts related to knowledge visualization from different domains

Concept	Concept domain	Originator	Citations (Σ top 3)
Boundary object	Sociology	Star et al. [18]	2,083
Epistemic object	Epistemology	Knorr-Cetina [14]	1,919
Dynamic affordance	Management	Cook and Brown [2]	1,523
Transitional object	Management	Eden and Ackermann [3, 4]	1,200
Notation criteria	Philosophy (of art)	Goodman [8]	1,120
Cognitive dimensions of notation	Computer science	Green [9]	110
Confection	Information design	Tufte [21]	924
Immutable mobile	Sociology	Latour [15]	860
Visual language	Instruction	Horn [12]	499
Conscription device	Sociology	Henderson [10]	366
Representational guidance	e-Learning	Suthers [20]	324
Diagrammatic reasoning	Logic	Peirce [11]	283
Visual hybrids	Art history	Elkins [5]	113
Visuospatial reasoning	Psychology	Tversky [22]	100
Affiliative object/working artifact	Management, anthropology	Suchman [19]	200
Object oriented/mediated collaborative action	Management	Kaptelinin [13]	600
Scaffold	IT/management	Orlikowski [16, 17]	300

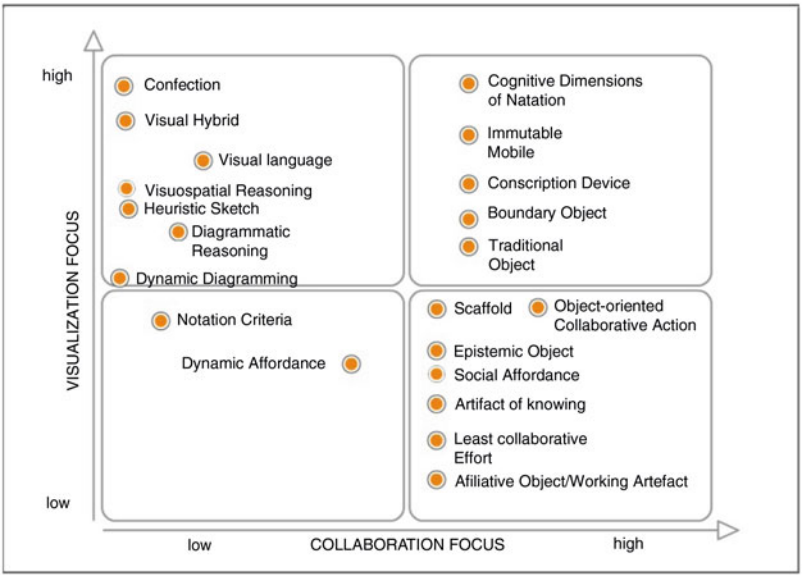

Fig. 1.2 A segmented overview of the key concepts for knowledge visualization

Table 1.2 Requirements derived from the concepts

Derived KV principle	Base concepts	Main insight of the concepts
Visual variety	Confection; visual hybrids; visual language; boundary object; notation criteria; cognitive dimensions of notation	An image that is able to capture and convey the knowledge of different people requires different ways of expression, ranging from simple sketched marks to complex rich visual metaphors contained in a single image
Visual unfreezing	Immutable mobile; boundary object; conscription device; notation criteria; cognitive dimension of notation; transitional object	To be useful for knowledge sharing and collaboration, a visualization must be able to be switched from a fixed mode to a flexible, modifiable mode and back
Visual discovery	Diagrammatic reasoning; visuospatial reasoning; dynamic affordance; representational guidance; conscription device; cognitive dimensions of notation	A visualization for collaboration must provide assistance for reasoning, reflection, and linking items in new ways so as to facilitate new discoveries from the shared insights
Visual playfulness	Representational guidance; diagrammatic reasoning; transitional object; conscription device, scaffold	In order to overcome rigid assumptions or role definitions and narrow perspectives, the visual should provide playful mechanisms to reframe issues and cajole participants into a different mindset and thus generate new insights and intensify collaboration
Visual guidance	Representational guidance; transitional object; boundary object; diagrammatic reasoning; dynamic affordance, affiliative object, scaffold, mediated collaborative action	The visual has to fulfill a dual role of not only capturing and structuring contributions, but also of providing a process of doing so in a useful sequence of actions

Compared with the original list of KV attributes presented earlier, we notice that visual playfulness is a new item, while visual variety, visual unfreezing, and visual discovery, as well as visual guidance are existing ones that are confirmed. Based on these attributes we can now provide a normative definition of what a KV should amount to, namely a communicable image, consisting of various visual notations, that is interactively annotated in a playful yet systematic manner and leads to new discoveries while remaining flexible to incorporate future revisions and insights.

In the next section, we present a few of the above-listed seminal concepts in more detail to show how they contribute to the emerging principles of KV.

1.4 Select Seminal Concepts in Detail

To illustrate the principle of *Visual Variety*, we can use Elkin's idea of *Visual Hybrids*, Tufte's concept of *Confection*, and Latour's notion of *Immutable Mobile*:

A *visual hybrid*, according to Elkins [5] is a graphic notation system that not only relies on one image genre, but combines two or more visualization formats (such as graphs, charts, tables, diagrams, genealogical trees, etc.). According to Elkin: "Especially given the hurtling development of new image technologies, mixed images can be said to be the norm rather than the marginal exception" [5, p. 91].

Very close to this notion is the idea of a visual confection. A *confection* according to Tufte "is an assembly of *many visual events*, selected from various streams of a story, then brought together [. . . .] Confections illustrate an argument, present and enforce visual comparisons, combine the real and the imagined, and tell us yet another story" [21, p. 121]. "Confections are not direct representations of pre-existing scenes, nor are they the result of placing data into conventional formats such as statistical charts, tables, or maps" [21, p. 122]. Tufte himself thus envisions that there are other visualizations than simple data or information representations.

Also, Latour's concept of immutable mobiles emphasizes the need for visual variety defining such artifacts as consisting of "*figures, diagrams, plates, texts, silhouettes*." [15, p. 37].

Latour's concept can also be used to explain the concept of *Visual Unfreezing*. Inscriptions are mobile as their elements can easily move, but these inscriptions become immutable and fixed on paper, once they have been confirmed by all participants.

Star and Griesemer's concept of a *Boundary Object* also emphasizes this dual nature of collaborative artifacts. Boundary objects, according to Star and Griesemer [18], are "both *plastic* enough to adapt to local needs and constraints of the several parties employing them, yet *robust* enough to maintain a common identity across sites." Boundary objects are weakly structured in common use, and become strongly structured in personal use. They may be abstract and conceptual or concrete and specific. They have different meanings in different social or professional contexts, but their structure is common enough to more than one professional community to make them recognizable means of translation.

The principle of *Visual Discovery* is not unique to the domain of KV, as detecting new patterns is also the main aim of the field of information visualization. In the KV context, the pursue of novel insights takes on a different form, as they are generated not out of the analysis and mapping of mass data, but rather visualized individual and collective views, opinions, assessments, and analyses.

This notion of insight through a process of interacting with a visual is probably best captured in the concept of *Diagrammatic Reasoning* that was first introduced by Charles Peirce [11]. The visualization becomes a think tool with which an individual or a group tackles a difficult problem. A simple example of diagrammatic reasoning is the positioning of elements according to their similarities in overlapping or containment circles, as in a Euler or Venn diagram. From this positioning, new insights can emerge, for example, groups with many versus groups with few members.

The principle of *Visual Guidance* is a particularly important concept for KV, as images in this context are not only used as representations of data but as catalysts for a collaboration process. Images act as signposts to what should be discussed and in what order. We find this attribute in Suthers' [20] concept of *Representational Guidance* in the context of e-learning and in Cook and Brown's [2] concept of

Dynamic Affordance in the management context. An image used in collaboration can act as a representational guidance, according to Suthers, by providing certain constraints to a discussion, by stimulating certain actions in a group, and by drawing attention to certain discussion topics (that are made salient graphically). Dynamic affordance, according to Cook and Brown's perspective, is what becomes possible when knowledge is used as a tool in the context of situated activity [2, p. 392]. These situated activities can be influenced through artifacts that invite participants to do one thing rather than another. Visuals thus provide affordances to steer the discussion in a particular direction.

Regarding the new principle of *Visual Playfulness*, we can—for instance—use Eden and Ackermann's notion of *Transitional Objects*. In their book on strategic management, Eden and Ackermann [3, p. 71] state that to do something enjoyable together can make collaboration easier; for example, tinkering with a strategy visualization used as a transitional object. Used in this provisional, exploratory or playful way, the visualization encourages an open dialogue and is capable of change by the group in real-time [3]. According to Eden and Ackermann, the participants who interact in this way waste less energy in impression management and are more immersed in their knowledge exchange than they would otherwise be. In this way, playfulness can be conducive to productive collaboration.

1.5 Implications

In terms of *practical implications*, the principles derived from the review of seminal concepts can be used as a checklist for group facilitators in the preparation stage of their work. They can use the identified attributes to evaluate or improve their discussion templates and thus make them more conducive to knowledge elicitation, integration, and application. More specifically, the five principles derived above can be used to check questions before knowledge creation, sharing, or application session, as exemplified below:

- *Visual variety*: Have you provided a sufficiently rich visual vocabulary that enables participants to express their ideas through various ways, such as through diagrams, sketches, metaphors, or simple text additions?
- *Visual unfreezing*: Have you incorporated ways in which certain states of a collaboratively drawn visualization can be captured and 'frozen' for later reference? Are there clear criteria when a frozen visual can be reelaborated and changed again?
- *Visual discovery*: Does the visual template provide affordances to connect elements in a new way or look at the big picture and detect new patterns?
- *Visual playfulness*: Does the visual invite participants to change perspectives, assume new roles, immerse in the collaborative effort, let go of assumptions or otherwise reframe issues creatively?
- *Visual guidance*: Does the visual offer a clear 'roadmap' of how it should be iteratively populated or completed? Is it clear where to start in the visualization and how to proceed?

In terms of *theoretical implications*, we have seen that in spite of their great differences in background, the examined concepts have an astonishing congruence with regard to the underlying mechanisms that they discuss. Anyone working on a future theory of collaborative KV is thus well advised to venture outside the realm of his or her own discipline and make use of the insights generated in such diverse disciplines as design, instruction, sociology, psychology, or art history. In this way, the domain of KV could also make this often dispersed knowledge accessible to scholars and practitioners alike.

1.6 Conclusion

In this chapter we have made an attempt to define the requirements of a KV that deserves the label. We have done so based on our practical experience [6, 7], the cognitive and collaborative dimensions framework [1, 9], and based on seminal concepts in the literature on collaborating with artifacts [2–5, 8–12, 14, 15, 18, 20, 21]. This has resulted in an extended list of requirements for KVs that we captured in five KV principles. These principles can be used to assess or improve KV templates used in knowledge-sharing tasks of teams.

In future research, we would like to see which of these requirements are in a trade-off relationship with one another and how they can be achieved through the help of interactive visualization software and adequate facilitation interventions.

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