

## Research Article

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# Co-Designing Visualizations for Information Seeking and Knowledge Management

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**Abstract:** Creativity is a crucial factor in finding novel and useful visualization and interaction techniques, but its emergence is contingent on the right conditions. The focus of visualization research has traditionally been on techniques, and to a lesser degree on the process of creating them with domain experts and end users. This paper focuses on the collaborative design of visualizations for information seeking and knowledge management. The difficult, yet common challenge in any visualization project is to find meaningful visual representations and useful interaction techniques to carry out complex analysis tasks. The unique difficulty for preparing co-design activities for visualization lies in the gap between the abstract nature of data and the concrete form of visual representations. To bridge this gap, our co-design framework for visualization places particular emphasis on actors, activities, and artifacts as categories that expand the focus of visualization design beyond the traditional triad of users, tasks, and data. Drawing from general co-design principles, the framework is developed and validated during the course of two case studies in the context of information management systems and library collection databases. Based on observed patterns during the case studies, practical tactics provide advice on carrying out co-design in information visualization.

**Keywords:** Co-design, Information Visualization, Methodology, Knowledge Management, Information seeking, Human-Computer Interaction

## 1 Introduction

Moving beyond the confines of their own discipline, information visualization (infovis) researchers and designers are exploring the potential of visualization in various new contexts. Numerous visualization projects have already been pursued in collaboration with other fields, such as the digital humanities (e.g., Hinrichs et al., 2016; Jänicke et al., 2015; Koch et al., 2014). These projects demonstrate the value that visualization can bring to data-intensive work in a widening range of domain-specific contexts. The benefits of such collaborations go both ways. Consider the surge of visualization in journalism, which on one hand has sparked entirely new forms of news reporting and telling stories. On the other hand, the use of visualization in journalism is also tightly linked with technical (e.g., Bostock et al., 2011) and conceptual innovations (Boy et al., 2015; Brehmer et al., 2014; Hullman et al., 2013; Segel & Heer, 2010) that were fostered by cross-disciplinary collaborations. As visualizations are being designed in various academic and applied areas, infovis research benefits not only from the demonstrated evidence of its utility, but also from the diverse experiences in the encounters with ‘other domains’. For this research, we collaborated with information professionals to incorporate their unique experiences that are related to information seeking and knowledge management, activities that have not been in the focus of infovis research so far.

Considering this rise of interdisciplinary visualization there is a growing interest in joint research and design projects, in which visualization opportunities are linked up with particular problems in an application area. Reflection on this type of visualization work has already led to multiple process models (e.g., Munzner, 2009; Sedlmair et al.,

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2012; McKenna et al., 2014; Meyer et al., 2015). However, there is relatively little reflection on the specifics of cross-disciplinary collaborations that involve domain experts into the process of visualization design. The models that have been introduced so far position design firmly in the hands of the experts. The input of the collaborators is mostly sought at the beginning, when the design goals are formulated, and towards the end during validation of the resulting visualizations. The core of any visualization design is still the dominion of visualization researchers and designers.

Yet, the visualization community has a keen interest in its various users and stakeholders. There has been promising research on tools and systems aimed at novices to conceive and create their own visualizations (e.g., Viégas et al., 2007; Viégas et al., 2009). In addition, studying how people with no visualization experience use ‘non-technological’ means to construct visualizations can provide valuable insights for the design of authoring tools (Huron et al., 2014). In the development of visual information systems there is little experience with involving the prospective users into the very generation of visualization idioms. This is where our work sets in. Drawing from our own and others’ experiences with co-design (Sanders, 2008), we seek to devise a design methodology that deeply involves stakeholders with varying backgrounds into the design process. In this paper, we develop and evaluate an approach to visualization design that emphasizes

- the continuous involvement of actors with domain expertise,
- the deliberate design of communicative-generative activities, and
- the importance of evocative artifacts as translational aids.

To explore these aspirations, we report on two case studies in the context of information systems: knowledge management and digital libraries. Incorporating the experience and expertise from knowledge management and information seeking expands the empirical foundation for co-designing visualization and for validating the proposed approach. More generally, the insights from these two studies also form the basis for practical tactics to guide co-design in library and information science.

## 2 Background

In the following, we introduce the concept of co-design, discuss its specific manifestations in computing, especially interaction design, and reflect on design-related research in infovis.

### 2.1 Co-Design

The term co-design goes back to the marketing notion of co-creation, which describes a shift in the value generation traditionally carried out by manufacturers of products to their respective consumers (Prahalad & Ramaswamy, 2004). Critical building blocks for this shift to happen are the possibility for users to engage in a dialogue and the availability of relevant information. This change in marketing coincides with an extensive trend across the economies towards services (Vargo & Lusch, 2004). The ‘service-dominant logic’ frames any kind of value exchange as a relational exercise, which primarily transfers skills and knowledge, while goods or services are merely viewed as carriers. The relationship between providers and customers is established and maintained through encounters and joint activities (ibid). We seek to explore the interactions among various stakeholders during visualization design and their potential for the co-creation of visualization concepts and artifacts.

In the context of design, the ideas of co-creation have taken the shape of what is known as *co-design*, with strong linkages to the Scandinavian tradition of participatory design (Muller & Kuhn, 1993). Co-design is a well-documented process during which designers, developers, researchers, domain experts, and other stakeholders collaborate to carry out design work. It is based on participatory principles and aims at the cooperative solution of a design problem (Sanders & Stappers, 2008). Especially, the joint making of artifacts using probes, tools, and prototypes has been identified to be crucial for the different phases of the design process (Sanders & Stappers, 2014). On the one hand, artifacts serve as objects that mediate sociality (Knorr Cetina, 1997) and, on the other hand, they can act as evocative examples that spur creativity throughout the design process (Herring et al., 2009). It is especially the social and creative aspect that

is essential in co-design. The principles of co-design have gathered interest in a broad range of domains, from human-computer interaction (Muller & Druin, 2002) and assistive technologies (De Couvreur et al., 2013) to service design (Steen et al., 2011; Pirinen, 2016) and urban planning (Al-Kodmany, 1999). A common principle across these disciplines, in which co-design has been taken up, is the deliberate identification and inclusion of relevant actors into joint design processes.

Involving users in the design of information systems has already been discussed as user participation (e.g., Hartwick & Barki, 1994; Bødker, 1996). As a basis for mutual learning and collective problem-solving, the notion of ‘informed participation’ describes the conditions supporting participants to “construct new knowledge collaboratively” and providing the “resources that enable users to generate new ideas” (Fischer & Ostwald, 2002). Akin to the way designers and developers bring in their prior experiences from related projects, the stakeholders bring in their own domain knowledge. The focus of design then lies not on the resulting system, but the structure of the encounters such as situations and environments that empower all participants to express themselves and jointly create solutions (Fischer, 2003). This approach has some resemblance to agile software development, in which users become critical experts that are often integrated into the team (Cockburn & Highsmith, 2001). When people are involved in the design of artifacts that they would be using, the ownership typically increases (van Rijn & Stappers, 2008), and designers and developers achieve a deep understanding of the relationship a stakeholder has with the design problem. However, even though co-design techniques are well-established in a number of technical, creative, and academic disciplines (e.g., Rijn & Stappers, 2008; Sanders & Stappers, 2008; Visser et al., 2005), there has not been any research explicitly studying co-design principles in the domain of infovis.

## 2.2 Design and InfoVis

We are witnessing a growing interest in the process of collaborating with domain experts to jointly come up with visualization techniques and evaluate their capacity to support analysis. This approach to infovis research can be understood as a design-based approach. The notion of *design orientation* (Fallman, 2003) offers a pragmatic approach to research, during which generative activities such as sketching, collaging, and prototyping form a dialogue between different stakeholders allowing for the collaborative production and exchange of knowledge. We are building on designerly ways of knowing (Cross, 2001) in that we hope to generate knowledge about the artificial world of infovis and how to create, change, and maintain it collaboratively with stakeholders.

There is a thickening line of infovis research that considers the research and design process itself. For example, the nested model provides helpful advice where to position a research project by guarding against threats to validity at different levels (Munzner, 2009). The design study methodology comprises three main phases of applied visualization research with practical suggestions and pitfalls (Sedlmair et al., 2012). Expanding on these efforts, the design activity framework places particular emphasis on the non-linearity of research activities carried out in visualization design studies (McKenna et al., 2014). In these models, the research activity is carried out by visualization experts and the primary object of study and scrutiny is the resulting visualization system. We are interested in building on these approaches by examining the role of artifacts, not as ends of a design process, but as means for a mutual exchange of knowledge and the collaborative creativity in infovis design.

Visualization research has already started to explore the relationship between creativity and infovis. For example, domain-specific visualizations may not only trigger insights, but also stimulate creativity during brainstorming (Dove et al., 2013). Creativity techniques have also been successfully introduced into user-centered visualization design (Goodwin et al., 2013). While the former study did not aim to create visualization techniques, but rather new ideas for products and services, the involvement of domain experts in the latter study was limited to early input on requirements and late feedback on prototypes. However, the recent rise of interdisciplinary visualization research at the intersections with the sciences and humanities shows how close collaborations can produce new kinds of knowledge. Reflections on a collaboration between visualization researchers and literary scholars have led to a recognition of the social and organizational factors going into the design of visualizations (McCurdy et al., 2016). This thinking resonates with our own experiences with collaborative visualization design, during which reciprocal shaping and guided emergence of ideas can take place. We are curious to examine how domain experts can be more closely integrated into the core design phase when visualization concepts are being generated, discussed, and iterated.

## 2.3 Towards Co-Design in InfoVis

Creating useful visualizations for particular domains can be a challenge due to the various kinds of knowledge, vocabularies, requirements, and expectations involved. Traditionally, infovis design has been largely data-driven, i.e., the starting point and focus for a given visualization project was the data set at hand. Visualization developers would look for data patterns and generate visual encodings to represent the properties that are pertinent for a given application area. Based on the type of data set, its structure, dimensionality, and size, specific visualization techniques would then be considered to be more adequate than others. Only at the very end of a project, prospective users would be involved to validate the resulting visualization. Quite often this approach has led to visualization techniques that may have been technologically advanced and appropriate for a well-defined data type, but often enough they were not well adjusted to the real-world context, where a multitude of data sets of varying quality and completeness are the norm.

With an increasing recognition of the need for user-centered design, this approach has been largely overturned and reversed. The people meant to be using the visualization after it has been implemented are increasingly consulted at the very beginning of a visualization project, to better understand the needs and requirements they have before the design process unfolds. An important outcome of such user-centered visualization research has been the characterization of the tasks in various fields of practice, which has led to a considerable number of task typologies each aiming to systematize a wide variety of data-analytical practices at different levels of abstraction (e.g., Brehmer & Munzner, 2013; Lam et al., 2018; Schulz et al., 2013) including task characterizations for specific data types (Kerracher et al., 2015; Pretorius et al., 2014). While the understanding of what a task is can vary considerably (Rind et al., 2014), this research is important groundwork for the design of user-centered visualizations. However, the focus on arriving at clearly delineated and domain-agnostic tasks tends to construct a clarity that arguably is not reflected in the messy and multiplexed data practices in specific work settings.

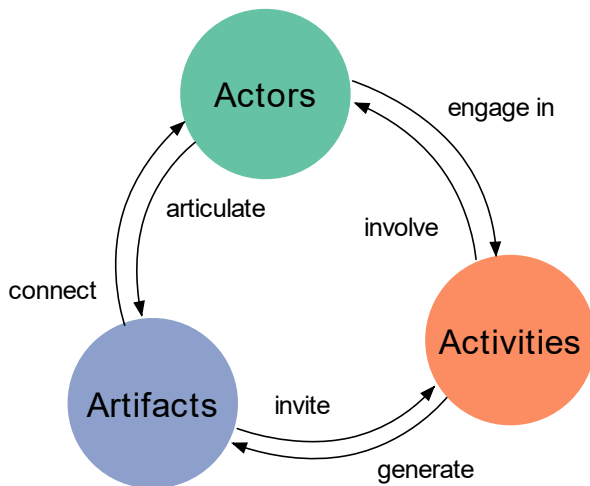
## 3 Bridging Gaps

We aim to develop an approach to visualization design that does not rely on general data models or task abstractions, but on the specific practices and preferences of the people using the respective information systems. This approach builds on previous experiences of co-design, which have already yielded solutions that are more sensitive to the context, for and in which they are being created and used (e.g., Sanders & Stappers, 2008). However, despite being well established in a number of fields, so far co-design has not seen much adoption in visualization. Reasons for this may be the abstract nature of many data sets and the complexity of analysis practices, which can make it challenging to pursue hands-on design activities with novices, or, more generally, the fact that visualization practice spans multiple disciplines itself, in addition to the specific disciplinary context of the target domain.

We contend that the main challenge for co-designing visualizations is that the collaborative creation of meaningful and useful visualizations for specific application areas implies three knowledge gaps and mismatches:

1. Visualization designers inherently have a limited understanding of the domain-specific practices that are to be supported or transformed.
2. Typically, the future users of a new visualization are experts in their domain, but have limited knowledge about the spectrum of infovis techniques that are feasible and the types of analysis tasks that a visualization may enable.
3. There is often an expectation gap between the visualization to be created on one side, and the available data and necessary tasks to be carried out on the other side. While stakeholders would wish to see a certain dimension across an information space, the underlying dataset may not include sufficient detail.

Our aim is to find ways to bridge these gaps in dialogic and generative encounters during which we collaboratively pursue pragmatic solutions. To achieve this, the participation of domain experts and prospective users in the design process should continue throughout the entire process: from formulating joint design goals and sketching initial ideas to discussing paper prototypes and evaluating the first software implementation. We aim to devise an approach to visualization design that leads to a structured and open process, which is meant to enable a continuous, creative exchange between domain experts, visualization designers, current or prospective users, and other stakeholders.



**Figure 1:** The co-design framework for information visualization suggests a joint consideration of actors, activities, and artifacts in an integrated design process.

To structure and plan the co-design process as a productive and on-going dialogue, we propose to expand the scope of visualization design by considering more broadly the diverse set of stakeholders as *actors*, the entire design process as a connected series of *activities*, of which each involves the joint creation and critique of *artifacts* (see Figure 1). The overarching research question is whether this constellation proves to be a viable framework to guide the co-design of visualizations in support of knowledge management and information seeking. In addition, with actors, activities, and artifacts as key components of the co-design framework, several practical questions arise:

1. To which degree can roles of the different actors be shifted to encourage mutual knowledge exchange and idea generation?
2. What is the purpose of artifacts in facilitating collaborative design of visualizations and discussions of the outcomes?
3. How can a series of joint activities be planned and structured to enable fruitful and effective co-design that addresses design goals and research questions?

In the following, we outline how a deliberate consideration of actors, artifacts, and activities can provide a scaffolding for finding answers to these questions in the context of specific design studies.

### 3.1 Actors

Actors refer to all the people involved in the course of a design study. The notion of ‘users’ in infovis tends to frame the people for whom visualizations are being designed as passive subjects of visualization research that one draws from as a resource to gain user requirements and to evaluate visualization prototypes. We argue that we need to shift this role entirely, and devise ways to support collaborators to become co-creators of the tools that they will use. Following from this, we view current and prospective users of visualizations as subjects in the philosophical sense, as thinking, feeling, and acting beings. It is the ambition of co-design to involve them as full collaborators throughout the process. This does not mean that they become visualization experts, but that the design process needs to be conceived in such a way that collaborators can meaningfully contribute to it.

The actors of each design study fall into two core groups:

- The **infovis team** consists of researchers, developers, and designers with backgrounds in computer science, interface design, psychology, and related fields. Throughout a design study, people in the infovis team act as facilitators and participants in the design study.



- The **domain group** are collaborators in the design study, with less experience in infovis, but with everyday experience and professional expertise in the target domain.

While the infovis team is most often part of a research group or a design studio, the stakeholders in the domain group can have diverse affiliations and backgrounds. In both groups there may be different roles and responsibilities with regard to the design study, which need to be considered when planning co-design activities. For example, in the domain group there would be one person who can be considered the project owner, with a vested interest in making the collaboration with the infovis team succeed. They are the primary contact, and they are often the person one can consult to understand the social roles of the other participants. Additional roles in the domain group can be maintainers of the technology in use (e.g., a library database), and the current or prospective users (e.g., library patrons). The composition of the groups can change over the course of the design study and in the different activities to be carried out.

### 3.2 Artifacts

Artifacts are an essential component in co-design. For the purpose of this research, we understand artifacts as any digital or physical object deliberately created during the co-design process. They create a visual and conceptual reference system for each design iteration. If the design problem has a direct relationship with a physical space or object, the co-design process can make use of these physical properties. Quite different from this is the preparation of artifacts for co-design in infovis. The particular challenge here is the contrast of abstract data as raw, yet elusive material and the necessity to transform it into a physical object that is graspable by stakeholders and easy to experiment with in co-design workshops, so stakeholders are put in a position to build and visualize their ideas with these artifacts.

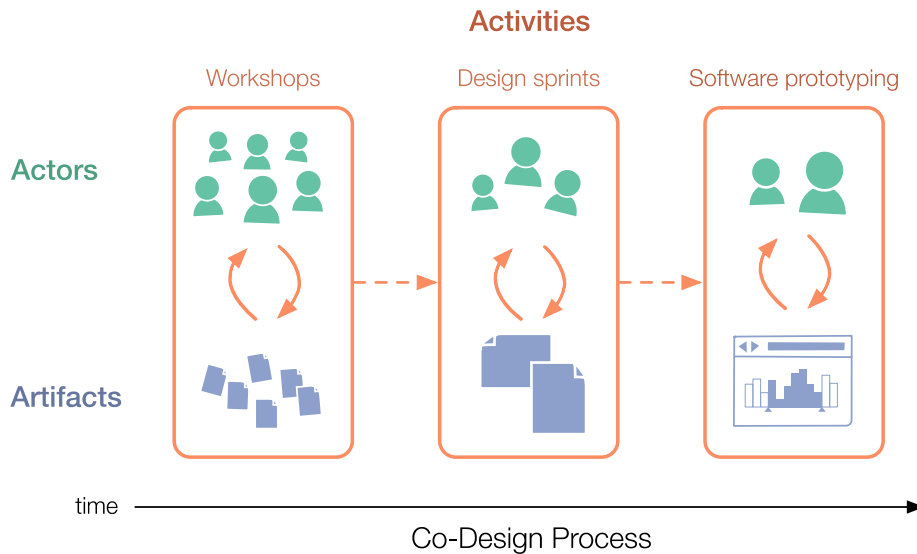
The creation of these tangible artifacts is a design task in itself. Data excerpts need to be selected and translated into visual or physical entities that are meaningful and understandable by the stakeholder. In a co-design process, all artifacts are designed objects, in a sense that they have a unique purpose in the creative process and convey a specific meaning. However, it is important to distinguish the different roles of the artifacts as they can easily be misinterpreted:

- **Evocation:** Artifacts initiate the design process and trigger imaginations.
- **Articulation:** Artifacts help participants to express a concept in a workshop.
- **Prototype:** Artifacts serve as a semi-functional interpretation of a concept.

An artifact as an *evocation* has a symbolic role in the co-design process. These can be extremely vague artifacts like mood boards that attempt to communicate a certain emotion. Evocations can also be much more concrete, for example, excerpts of databases that provide an impression of the data. As such, the role of the artifacts is to bring abstract data into the world and make it tangible and malleable. While this seems to be straightforward, the selection and presentation of the data excerpt is in itself a design task. The excerpts need to be open for creative interpretation, they must be expressive and understandable to be immediately used by the workshop participants.

An artifact as an *articulation* is the result of the synthesis and transformation of evocations performed by the workshop participants. The articulations enable the participants to express concepts and ideas in the form of concrete objects. As it is difficult to verbalize graphical ideas for visualizations, it is crucial to present the participants with visual and physical material that enables them to make statements appropriate for the communication of their ideas. The evocations are an important prerequisite for the generation of articulations, which are statements that represent a certain idea, connection, or concept.

Articulations need to be translated and interpreted by the infovis team and turned into *prototypes*. This is a highly integrative approach as results from the workshops can be contradictory. Furthermore, the articulations are expressions of ideas. They usually do not form a coherent solution to a specific problem. The design of the prototype is a synthesis of various, sometimes conflicting ideas. The results of this phase rely more on the professional design process performed by the infovis team. They are not finalized systems but rather more coherent and more integrated iterations. As prototypes already simulate a finalized system, they can be subject to rigorous testing and feedback.



**Figure 2:** The co-design process comprises a series of connected activities, of which each are defined by the participating actors and artifacts.

### 3.3 Activities

As illustrated in Figure 2, a co-design process consists of multiple activities, each of which have distinct aims involving specific sets of actors and artifacts. Central to our approach are open and creative workshops during which members of the infovis team and the domain group work closely together to generate ideas and discuss concepts. In these workshops, participants use various materials to produce and exchange individual articulations from the evocative artifacts provided. In the area of infovis this co-design process can be characterized by three idiosyncrasies:

1. The process is focused on negotiating the relationship between data, stakeholders, and their needs. Designers become mediators between these actors and artifacts. This mediation takes place during activities, which the artifacts are specifically designed for.
2. During the workshops the complexities of the data and the particular needs of the actors are bridged. A challenge in the design of these workshops is a reasonable balance between addressing the specifics of stakeholders and leaving room for surprise in the design process.
3. User needs, data sets, and tasks are not static entities, but are continuously constructed and performed (Drucker, 2013). The activities are deliberately structured to help the participants utilize artifacts to openly negotiate the various roles and states of these entities.

We propose a design process that consists of formalized activities as well as open-ended ones. The formalized activities are based on existing methods of user experience design (ISO 9241-210:2019). Contextual inquiries or shadowing techniques can be used to understand the basic scope of the use cases. Software prototyping and expert evaluations generate qualitative insights on the success of specific design decisions. Our approach to the open-ended, more creative activities is more unique and a contribution to the ongoing debate on design methodologies. We treat the setup of each workshop as a design problem, for which the following sets of questions can guide the planning:

- Where are we at in the design process? What do we want to achieve now?
- Who is taking part in the activity? What kind of experiences are particularly relevant?
- How can we turn data into tangible artifacts? How can we translate user needs and tasks into stories and activities? What are adequate materials, instruments, and props for this?
- How can the participants be empowered to develop ideas and make decisions?

Fundamental to this approach are the concepts of empowerment, ownership, and capacity building. If an actor understands both the limitations and the possibilities of the data set, and has an idea about the mechanisms of visual

representation and interaction, they are better able to define and design visualizations that meet their needs and reflect the scope of the data set. While each activity is defined by the selection of actors and artifacts, the concatenation of activities forms the overall design process. Results and insights generated in one activity inform the subsequent ones.

In the following two sections, we report from two co-design studies, involving comprehensive databases, a diverse set of stakeholders each with particular perspectives and expectations. It is important to note that we, as researchers, assume the hybrid role of actors and observers. Akin to the notion of action design research (McCurdy et al., 2016), we are not merely passive bystanders but are embedded and involved in the activities constituting the research and design process. We made observations during workshops and reflections on all other activities, we analyzed the visual artifacts, such as collages, sketches, and paper prototypes, and collected feedback during the activities and in personal communications. While the two case studies are similar in scope and domain, they differ in that the first case study targets a more specialized user group, while the co-design carried out in the second case study aimed at a broader target audience. Both case studies followed a similar order of activities, the selection of artifacts and involvement of actors differed considerably.

## 4 Case Study 1: Knowledge Management

The first case study was a research cooperation with a governmental department over the course of nine months. The department that relies on a knowledge management system, which is based on a proprietary database and user interfaces, and has become an essential tool for running the department and is increasingly used for strategic planning. However, like most proprietary systems, it lacks an adequate interface that allows the users to easily visualize and interact with the data. So, there was a significant need and opportunity to combine a user-centered design approach with the development of meaningful data visualizations. Our aim was to create visualization interfaces that not only represent the data but that are also integrated into the analysis practices at the department. See Table 1 for an overview of the main elements of the co-design process carried out in this case study.

**Table 1:** The selection of actors, activities, and artifacts of the first case study.

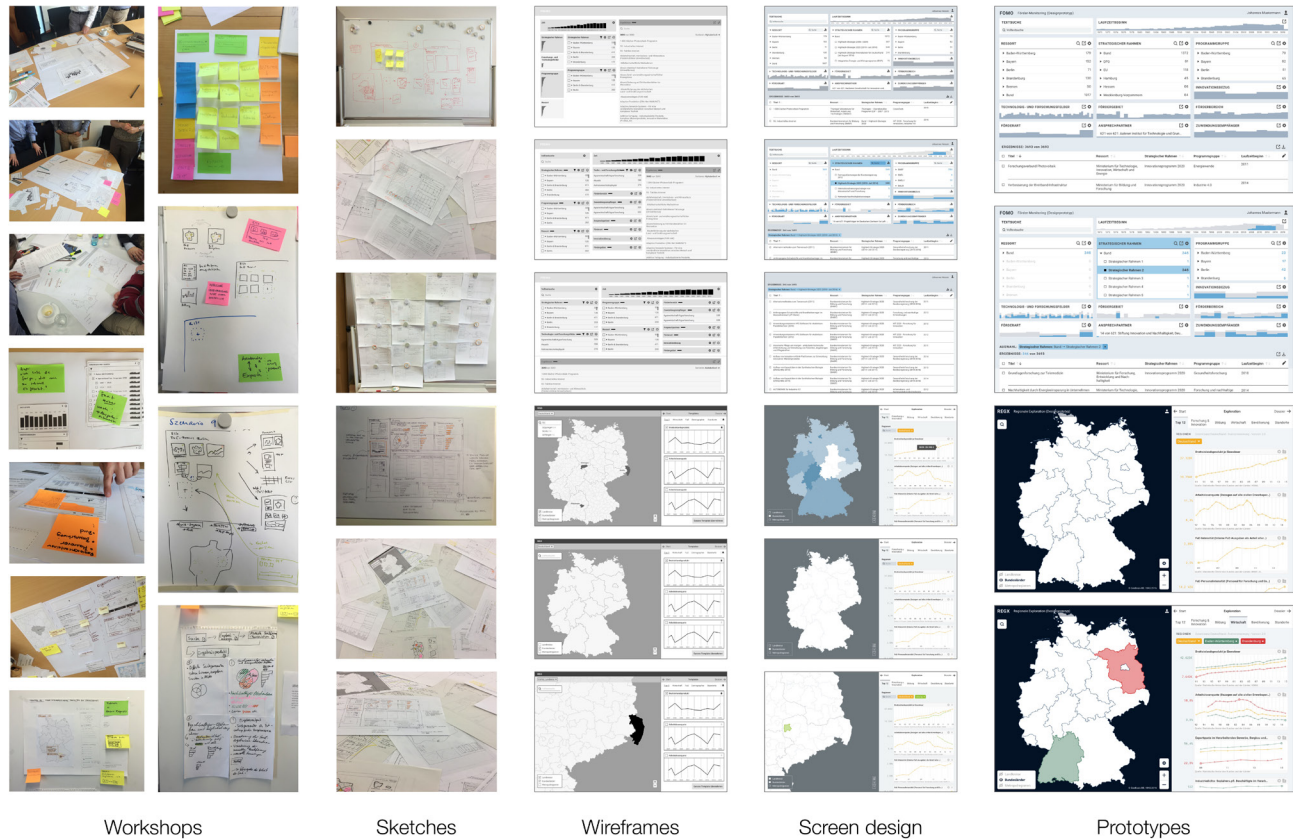
Actors	Activities	Artifacts
Infovis team	– Expert interviews	– Mood boards
– Principal investigator	– Contextual inquiries	– Infovis cheat sheet
– Interaction designers	– Workshops	– Paper templates
– Software developer	– Design sprints: Sketching, Wireframing, Screen design, Feedback sessions	– Data excerpts: tables & factsheets
Domain group	– Software prototyping	– Sketched user interface elements
– Managers		– Paper prototypes
– Data experts		– Screen designs
– Clerks and interns		– Interactive prototypes
External collaborators		

From the beginning, the **actors** in the project were clearly defined: The infovis team consisted of a principal investigator, two interaction designers, and a software and visualization developer. Additional support was provided by external collaborators – especially for the evaluation of the project. The domain group were representatives from the governmental department. The members of the group came from various levels of the department and included managers, domain experts but also clerks and interns. Hence, we had access to a wide range of collaborators who had a very diverse working relationship with the knowledge management system.

The project plan followed a user-centered design process (ISO 9241-210:2019) and had several project stages. We conducted interviews and contextual inquiries, workshops, design sprints, prototyping, and evaluations. Our collaborators established contact with a total of 14 representative users, who were visited at their workplace at the



governmental department over a period of three weeks and interviewed by members of the infovis team about their professional role, kind of data-related activities, and observed during typical activities with the systems. The findings collected in the interviews were recorded in keywords and evaluated with the help of affinity diagramming. A total of five topic areas crystallized as clusters: purpose, subjective situation, interface/UX, data/representation, and feature requests. Within these subject areas, various requirements could be defined that served as guidelines for the subsequent design process. For the purpose of this paper, we now focus on three specific situations where our framework for co-design made a particular difference and where we were able to usefully structure the relationship between actors, activities, and artifacts. There was a high degree of continuity between all activities; insights and results of the first stages directly influenced the design and implementation of the later ones (see Figure 3).



**Figure 3:** The material used in early workshops was used by the participants to formulate scenarios and devise use cases for visualization. During additional workshops, sketches of refined visualization ideas were shared with the collaborators to discuss the overall directions of the joint project. Communication with the domain experts during successive design iterations was facilitated by the continuity of ideas being refined via wireframes and the final screen design. Core functionalities of the interface concepts were implemented in modular prototypes.

## 4.1 Kickoff Workshop

The initial workshop was the first formalized meeting between the infovis team and the domain group. At this stage, both groups did not have a great understanding of each other. The infovis team had very little knowledge of the technology and the tasks, roles, and responsibilities within the domain group. On the other hand, the domain group knew very little about the design space, in general, and especially very little about infovis. The aim of the kickoff workshop was to establish a common ground and to develop a greater understanding of the respective other group. For this, the selection of the appropriate **artifacts** and **activities** was crucial.

The infovis team prepared a number of artifacts that created a foundation for the activities during the workshop. These evocations included general mood boards and reference projects, but also more specific items. Three were especially relevant for the implementation of the workshop.

- A “cheat sheet” for infovis contained an overview of the Gestalt laws and of visual variables (Bertin, 1983) with the aim to establish very basic knowledge of the infovis principles and support capacity building in the domain group.
- Paper templates contained simple graphic structures. The main visual element is a panel for sketching that is accompanied by a brief questionnaire regarding the sketch. As the knowledge management system contains geographical data, some templates also contained maps.
- Carefully designed data excerpts were provided as printed tables and factsheets to the members of the domain group. They would recognize the content that was extracted from the knowledge management system and that they could easily understand and visually interpret.

These artifacts were then utilized in three activities aimed to transform the **evocations** into **articulations**. The workshop participants were asked to utilize the artifacts to make their domain knowledge visible and to create expressions of their own ideas. Participants had also access to conventional workshop material such as pens, color pencils, stickers, and sticky notes and were encouraged to freely use all the material.

*Warm-up:* First we wanted to establish a certain level of understanding of infovis techniques. For this, we split the workshop participants into three different groups with an equal representation of members from the domain and infovis groups. We then asked the participants to visually compare two aspects of the data excerpt. For this, they could use the infovis cheat sheet. The aim of this activity was more focused on competence building than on the expression of ideas, but as we used real data, some workshop participants already came up with ideas that were used in the next activities.

*Show and find out:* The second and third activity during the workshop were very similar, they only differed in the assignment. The first assignment was to come up with a visualization that makes a certain aspect of the data easy to understand (“I want to show...”). The second assignment was already addressing aspects of the user interface: the participants were asked how a visualization could look like that answered a specific question (“I want to find out...”).

The workshops resulted in a number of artifacts that provided the infovis team with insights into the questions, tasks, and workflows of the domain group. The evocative artifacts enabled the domain group to articulate a number of concepts and ideas that would accompany the entire team throughout the project. Some of these articulations became points of reference for the design and prototyping stage and were often referred to during discussions. So even these very early articulations became very valuable for the development of the entire project.

## 4.2 Interface Sketches

Another crucial co-design situation was the paper prototyping stage. Here we were highly interested in gaining insights into the relationship of visualizations and user interface elements. We wanted to find out, which interface controls the users prefer and if new ways of working with the data could be envisioned. As evocative artifacts, the infovis team prepared roughly sketched user interface elements, such as search boxes, buttons, and sliders, but also more complex elements like maps, curated lists of metadata, or infovis design patterns. It was important that the visual appearance of the elements was “sketchy” to remind the participants that they are not dealing with finished design elements.

The procedure of the workshop was similar to the kickoff workshop. The participants were encouraged to transform the relatively vague artifacts into more concrete articulations that would express a certain approach to the design of a user interface. An interesting aspect of this situation was that the results were much more elaborate and could sometimes already be taken as a prototype.

The acceptance of these paper prototypes within the domain group was very high and provided the infovis team with a large number of specific insights and ideas for the next project stage.

### 4.3 Software Prototyping

As a result of the paper-prototyping workshop, we were able to identify the core functionality and visual components of the new interface. However, the main challenge of this stage was to integrate the different and, in part, contradicting ideas that were developed in earlier stages. For example, requests for high levels of flexibility and customizability stood in a certain conflict with the notion of intuitive ease of use. In order to create a coherent visual and interactive system, we had to make compromises and negotiate between different approaches. At this stage, the high level of involvement of the domain group proved to be extremely valuable. As the different members of the domain group were aware of the existing concepts and ideas and as these ideas also existed as articulations, it was possible to make consensual decisions for the final prototype. Technically, the system was divided into small functional units for rapid prototyping. This allowed for rapid development of a system with highly modular visualization components that were customizable by the users and that could continuously be tested and evaluated by the domain group.

### 4.4 Outcomes

At the end of the project, we conducted a qualitative evaluation with members of the domain group. We were interested in two main questions: 1) are the users satisfied with the final product, and 2) are the users satisfied with the overall design process?

While the answers to the first question provided a number of important insights for the further development of the software interface and the visualization elements (e.g., the importance of clear and concise explanations), the answers to the second question are more relevant in the context of this paper. We received very positive feedback for the process. A number of participants stated that they had acquired new competencies in the area of process management and infovis. Furthermore, almost all participants stated that they felt very involved in the process and were able to express their own ideas. One person called the process innovative and stated that it was actually fun.

These results from the first case study were encouraging and demonstrate the positive impact of co-design. The high degree of involvement of the different actors, the careful planning of activities, and the production of different artifacts resulted not only in the successful re-conceptualization of a knowledge management system, but also in the empowerment of the domain experts.

## 5 Case Study 2: Information Seeking

The goal of the second case study, which also lasted nine months, was to develop integrated infovis techniques for the exploration of a large and multifaceted digital library and to integrate these visualizations into a search interface. The project was a collaboration with a national library. In addition to collecting various types of media, such as books, magazines, catalogs, records, and sheet music, the library also maintains an authority file containing information on persons, organizations, and subject headings. The combination of the library catalog, the authority file, and a wide group of potential users provided a fitting context for applied visualization research. See Table 2 for an overview of the main elements comprising the co-design process during the second case study.

Akin to the first case study, the **actors** in the project were clearly defined. The infovis team consisted of a principal investigator, an interaction designer, and a software developer. Additional support was provided by external collaborators during the research and preparation phase, the implementation of the prototype, and the evaluation of the project. The domain group was also a diverse team that included managers, domain experts in library science, and library database users. Throughout the activities the number of participants of the domain group varied, but at all times at least one manager, expert, and user were involved.

**Table 2:** The selection of actors, activities, and artifacts of the second case study.

Actors	Activities	Artifacts
Infovis team – Principal investigator – Interaction designer – Software developer	– Expert interviews – Contextual inquiries – Workshops – Design sprints: Sketching, Wireframing, Screen design, Feedback sessions – Software prototyping	– Scenario sheet – Book covers, metadata displays, screenshots, portrait photos, maps – Collages – Paper sketches – Wireframes – Screen designs – Sketches of database schema – Functional prototype
Domain group – Managers – Experts in library science – Database users		
External collaborators		



**Figure 4:** At the beginning of the second case study, participants of co-creation workshops (left) were encouraged to create collages with sample material from a comprehensive bibliographic database. Accompanied in regular feedback loops with members of the domain group, the ideas were subsequently analyzed and synthesized into sketches, wireframes, and finally into a screen design and a fully functional prototype.



## 5.1 Expert Interviews and Contextual Inquiries

First, we needed to grasp the extent of the library collection as well as the expectations, needs, and problems of the stakeholders involved in the project. Since we did not have programmable access to the database at this point, we used the library website and existing OPAC (Online Public Access Catalog) interface to gather preliminary insights into the collection, its current representation, and the apparent architecture of the underlying database. We used these insights to prepare the subsequent steps: expert interviews and contextual inquiries.

**Expert interviews** with members of the domain group provided important background information on the structure, scale, and long-term evolution of the collection and database, as well as the relevant work practices such as documentation, indexing, and the usage of the OPAC system. The interviews were carried out as semi-structured interviews with a set of questions on each of these aspects. During contextual inquiries in the reading room of the library, we observed participants using the OPAC interface for various information tasks and learned about the strategies they employed and problems they encountered. After receiving consent from the participants, the observations took place one by one in the reading room of the library, while each session took about 30 minutes. Participants were asked to continue their research with the library system.

The key insight we gathered during this stage of the project was that the domain experts considered the collection to be particularly extensive and diverse. However, they were aware that the OPAC interface does not expose these characteristics and does not offer any tools for exploring the collection. The observations we made during the **contextual inquiries** with library patrons recruited in the local reading room confirmed this. We learned that people predominantly use search boxes and that they search the collection iteratively.

Based on the expert interviews and contextual inquiries we developed a set of scenarios, which described a fictitious user and a task they would solve or a question they would answer using the library's digital collection. The scenarios served two purposes during the remainder of the project: First, we used them to evaluate our concepts and to test whether our design proposals could be used to solve the tasks described in them. Second, they served as a framework for a series of co-design workshops with diverse actors.

## 5.2 Collaging Workshops

The participants of the workshops included a range of experts and non-experts from the domain group. The participants were then divided into groups of three or four and given a scenario sheet to create a paper prototype. In addition, we provided each group with **evocative artifacts** such as printed book covers, metadata displays, screenshots of the current OPAC interface, photos of persons, and maps. Every group was joined by a member of the infovis team, who would moderate the discussion, keep the group focused, and offer advice regarding exploratory search and infovis. Based on the scenarios, the first aim of this workshop was to translate the artifacts into articulations in the form of collages (see Figure 4, left). Afterwards, the results were interpreted by the other groups before being explained by the group that created it. This approach resulted in lively and controversial discussions between participants and helped us to further improve our understanding of stakeholder needs and preferences.

Based on the collages and discussion notes, we developed a set of design goals in close collaboration with members of the domain group. These goals would support us during the subsequent design stages. Most importantly, one insight was that the visual interface should permit both open exploration and directed search. The interface should be based primarily on interactive visualizations of the main facets, but still offer text-based search. The visualizations should function as both a tool for further exploration and for refining search parameters.

## 5.3 Concept and Design

In the next step, we conducted a set of team-internal workshops aimed to flesh out ideas derived from the collages, to check whether they would meet the previously defined requirements, and to assess whether they were technically feasible. During these workshops, we strongly relied on paper sketches, with which the workshop participants created

more refined **articulations** that enabled us to discuss and develop many different visualization types, information architectures, and user flows.

We then created wireframes of our proposed interface and presented them to the domain group. Since the feedback from this presentation was positive, we started refining the wireframes and created a visual design language for the overall interface. We also refined the methods of interaction, the links between the facets and the result space, and the information architecture. Next, we presented both the refined concept and the visual design. Feedback from this presentation resulted in further adjustments of the concept and some improvements of the visual design. As a final step, we evaluated the interface using focus group conversations with both experts and non-experts. Since the interactive prototype was not usable yet at this point, we provided participants with paper printouts of each screen. The evaluation revealed some flaws in our concept and some usability issues, which were addressed in a final iteration.

## 5.4 Data Preparation and Software Prototype

Working with a snapshot of the library's database proved to be more difficult than we had expected, which required considerable back-and-forth communication between the infovis team and the domain group. This process was further complicated by the varying quality of the meta data and by the sheer size of the database export. For the prototype it was crucial to find design strategies to display the large amount of data in the front end without overwhelming the user. It was therefore critical for the developer and designer to work closely together during the last stages of the design process to ensure technical feasibility. Sketches of both the database schema and the visualization concepts supported cross-disciplinary collaboration within the infovis team. The software prototype was finished and published as a web-based search interface<sup>1</sup> that was announced by the library via their social media channels and website.

## 5.5 Outcomes

Towards the end of this case study, we carried out a summative evaluation in the form of two focus groups and one expert interview and walkthrough. The main points were recorded as notes and subsequently analyzed using affinity diagramming. In addition, we regularly noted our own observations during activities throughout the project. The visualization interface was characterized by the participants of the focus groups as well as by the expert as an appropriate tool for explorative research in the library catalog. It was found particularly helpful when users want to work on new topics or find answer to general questions. The visualization along the three facets people, topics and time was described as relevant and understandable, but the interaction could still be improved in detail. Adapting the layout of the application could also improve interaction by placing more emphasis on the result set and thus linking it more clearly with the facets. At the same time, the interface expert warned against overloading the interface with features sacrificing its simplicity and accessibility. According to the participants in the focus groups and the expert, exciting and surprising findings are mainly the result of serendipitous findings.

In retrospect, our collaborative approach has enabled the mutual exchange of ideas and insights at the intersection of infovis research and library management. In the context of visualization research, the project has led to several ideas for integrating search and exploration for an extensive and diverse information space. Using interactive and interlinked visualizations to represent different facets in varying levels of detail is one possible method for improving the access to such collections. The positive response to the interactive prototype from our collaborators as well as external members of the domain group suggests that infovis techniques can be a useful supplement for text-based search. Throughout the co-design process, it was noticeable how the collaborators were able to comprehend the evolution of ideas between different activities. This had the effect of a sense of co-ownership of the interim and final results, in both the infovis team and domain group.

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<sup>1</sup> The prototype is available here: <https://dnbvis.fh-potsdam.de>



## 6 Findings

The co-design approach served as a scaffold for involving actors throughout the two case studies, selecting the appropriate artifacts, and devising meaningful and effective activities. In this section, we reflect on some pertinent patterns that we observed during the activities in both case studies. Key observations were noted in an online document and discussed by the infovis team after each activity. Our own observations and the feedback from collaborators and participants have been analyzed and aggregated into three major themes and synthesized as implications for co-design in infovis.

### 6.1 Diverse Backgrounds and Interests

The selection of actors in each co-design activity was deliberately carried out to reach a mixed and diverse group of stakeholders. Furthermore, during an activity we paid close attention to the composition of sub-groups to be diverse as well. This had the effect that everyone had the opportunity and, to some degree, the obligation to share and encounter different perspectives on the theme of the project. For example, varying familiarity with a given data set was actually conducive to the overall conversation as it encouraged the verbalization of insights and issues. In addition to differences in expertise, a variety of perspectives also resulted in a range of aspirations to be discussed and negotiated during the course of the co-design activities. We noticed that it was also useful to invite potential stakeholders, i.e., people who are not part of the infovis team or domain group, but who might be using a visualization in the future or who would in principle have an interest in the data. Having also people with no firm commitment towards the project, but rather a cursory interest in the topic provided an informed outsider perspective.

*Use knowledge gradients to encourage dialogue.* Involving actors with varying backgrounds and interests provides for a situation that encourages exchanges. Ensure a basic level of commitment and interest among participants, otherwise, there may be limited motivation to meaningfully contribute.

### 6.2 Bridging Difference and Building Capacity

While there were productive differences in expertise and experience in most activities during the case studies, the aim was to use these differences to encourage dialogue and making. To achieve this, we noticed that in most activities the artifacts played a very important part.

On one hand, artifacts such as book covers and bibliographic information sheets acted as translational aids for actors with different disciplinary and professional experiences. Entities that have a distinct nomenclature within and outside a specialized domain such as library science, would become relatively comprehensible. Being able to simply refer and work with printed images and text as samples from a comprehensive information space significantly lowered the threshold for outsiders to work with the data and talk about it.

On the other hand, providing printed samples of basic interface elements and visualization techniques built practical capacity among all actors to closely consider the building blocks of complex visualization systems. By creating interface composites using these printed paper templates, workshop participants were able to engage in the speculative making of visualization systems. Here too, it was not necessary to correctly name the different components, but rather to negotiate the kinds of analytic activities they would like to pursue with them.

*Introduce relevant and evocative artifacts.* Across the different roles—evocation, articulation, and prototyping—artifacts play an essential role in bringing people together with different backgrounds and providing support structures to contribute (Fischer & Ostwald, 2002). Regardless of the specific activity formats—from co-creation workshop to feedback sessions—the choice of artifacts should be carefully aligned with the aims of the project. While the artifacts being used and created do not necessarily need to resemble the interface or visualization they serve as proto-representations of data, as they already shape what kind of ideas can be articulated and exchanged. Because of this, the selection of artifacts becomes an important design decision with implications for the subsequent steps in the process.

### 6.3 Joint Ownership and Provenance of Ideas

The co-design process comprised several connected activities during which various insights and concepts were collectively developed by all actors.

It was our explicit goal to encourage everyone to engage in creative expression as well as discussions of the merit of emergent concepts. For all participants to feel comfortable to contribute it was important to work in an atmosphere of trust and openness. While this aspect hardly required particular intervention, in one instance, it meant to proactively moderate a discussion, during which a particularly verbose participant was dominating the conversation. Not all activities require the same degree of involvement from all actors. However, especially when a diversity of perspectives is being sought it has proven to be useful to be prepared for ensuring the contribution from everyone.

While a single idea cannot be linked to an individual actor, the results from one activity do inform the next steps. It was noticeable how the actors in the case studies were interested in comprehending the evolution of ideas all the way from initial sketches to functional prototypes. For this process to succeed, it was paramount to carefully and iteratively build on top of these intermediate results and communicate this process during the activities with our collaborators. While all participating actors assume a shared responsibility to exchange and shape ideas, it is in particular the role of the infovis team to record, analyze, and convey the results of activities and therefore moderate expectations of all actors. We noticed how the diligent and detailed communication of interim steps fostered the understanding of the project's progression and agreement with the design decisions going forward.

*Cultivate an atmosphere of trust and transparency.* In order to make the co-design process satisfying for all involved actors, it is essential to create the necessary conditions, in particular mutual respect and trust. As ideas and concepts are being developed collectively by all actors, it is important to trace the evolution of ideas between activities and instill a sense of co-ownership over the results.

## 7 Conclusion

There are multiple ways to approach information and visualization research involving other stakeholders. So far there has been considerable work on infovis *for* (i.e., visualization as a service) and infovis *by* (i.e., visualization as a tool) specific group of users. A recent surge of design studies, however, indicates the importance of infovis *with* a specific domain group (i.e., visualization as collaboration). The focus of our work has been on the latter. We wanted to examine how design studies in infovis can be carried out as continuously collaborative endeavors.

Based on established co-design principles developed in other design fields, we have proposed a co-design framework, which hinges on three basic components: actors, activities, and artifacts. According to this framework, a co-design process consists of a series of collaborative activities, during which diverse actors use evocative and meaningful artifacts as proto-representations of data to iteratively generate concepts for visual and interactive representations. We have applied, developed, and evaluated this co-design framework in the context of two consecutive case studies. In each case study, an infovis team was collaborating with stakeholders in the creation of novel visualization systems for the analysis and exploration of complex information spaces. As participating observers, we documented our own experiences as well as the responses from our collaborators in order to assess the viability of the framework for conceiving visualizations in close collaboration. Based on both the results as well as the responses from our collaborators, we can conclude that our co-design framework provides an effective approach to creating visualizations in close collaboration with domain experts. The deliberate consideration of actors, artifacts, and activities offered not only a useful way to think about infovis design with domain experts, but also proved an effective approach to plan and carry out a co-design project at the interface between infovis and information science. We have discussed prominent social patterns that occurred during the collaborative design of infovis systems and outlined practical tactics for bridging likely mismatches in expectation and expertise.

An important, if not essential, part of any design activity, is to decide on the scope of a project by identifying and articulating the problem. If we are to open up this process, we need to create the conditions for all collaborators to frame a problem according to their own perspective and preferences. By proposing a different nomenclature with this framework, we transformed contextual considerations of information visualization (users, tasks, and data) to central

concerns of the design process: actors, activities, and artifacts. We are intentionally blurring long-held distinctions: by talking about actors we emphasize that both users and experts should have the license to contribute ideas throughout the process. However, shifting roles does not mean dissolving differences. For infovis, co-design rather suggests a shift of responsibility from producing a final technique or system to structuring an entire design and development process. The results of the two case studies confirm the viability of co-design for applied visualization research that promotes the collaborative creation of useful and meaningful information visualizations that are owned and accepted by all stakeholders.

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