A Framework for Creativity Workshops in Applied Visualization Research

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Abstract—Applied visualization researchers often work closely with domain collaborators to explore new, useful, and interesting applications of visualization. The early stages of collaborations are typically time consuming as researchers piece together an understanding of domain challenges from disparate discussions, interviews, and meetings. A number of recent projects, however, report on the use of creativity workshops to accelerate the early stages of applied work, eliciting a wealth of requirements in just a few days of focused work. Yet, there is no established guidance for how to use such workshops effectively in the context of visualization. In this paper, we present the results of 2-year collaboration in which we analyzed the use of 17 workshops in 10 visualization projects. This paper's primary contribution is a framework for visualization creativity workshops. The framework 1) identifies a process model for using workshops; 2) describes a structure of what happens within effective workshops; 3) recommends 27 actionable guidelines for future workshops; and 4) presents an example workshop and workshop methods. Also, the creation of this framework exemplifies the use of critical reflection to learn about visualization in practice from diverse studies and experience.

Index Terms—User-centered visualization design, design studies, creativity workshops.

1 Introduction

A key challenge in the early stages of applied visualization work is to find pressing domain problems and to translate them into interesting visualization opportunities. Researchers often discover such problems through a lengthy process of interviews and observations with domain collaborators [33, 45, 61] that can sometimes take months. But, a number of recent projects report on the use of workshops to characterize domain problems in just a few days of focused work [14, 15, 16, 31, 51, 68]. When used effectively, workshops reduce the time and effort needed for the early stages of applied work, as noted by one participant: *"the interpersonal leveling and intense revisiting of concepts made more team progress in a day than we make in a year of lab meetings ... [the workshop] created consensus by exposing shared user needs"* [31].

The workshops that have been used to understand domain problems are **visualization creativity workshops** that deliberately and explicitly foster creative thinking among researchers and their collaborators to explore opportunities for visualization within a domain. Despite the reported success of such workshops, however, there is no formal guidance about how to design, run, or analyze them. For example, Goodwin et al. [15] provide rich details, but with a focus on their experience using a series of workshops in a collaboration with energy analysts. In contrast, Kerzner et al. [31] summarize their workshop with neuroscientists in one sentence even though it profoundly influenced the direction of their research. This lack of structured guidance leaves visualization researchers interested in using creativity workshops to piece together disparate and sparse workshop descriptions.

In this paper, we — a group of visualization and creativity researchers who have used a number of visualization creativity workshops — reflect on our collective experience and offer guidance about how and why to use such workshops. More specifically, this paper results from a 2-year, cross-institution, international collaboration in which we applied a methodology of *critically reflective practice* [4] to perform meta-analysis of our collective experience and research outputs from conducting 17 creativity workshops in 10 visualization contexts [14, 16, 15, 30, 31, 35, 51, 54, 55, 68], as well as a review of the creativity workshop literature from the domains of design [1, 12, 11, 32, 57], software engineering [23, 27, 28, 29, 38, 40, 42] and creative problem solving [10, 17, 19, 47, 53].

This paper's primary contribution is a framework for visualization creativity workshops. The framework consists of 1) a process model that identifies actions before, during, and after workshops; 2) a workshop structure that describes what happens in the beginning, in the middle, and at the end of effective workshops; 3) a set of 27 actionable guidelines for future workshops; and 4) an example creativity workshop and example methods for future workshops. We tentatively offer a secondary contribution: this work exemplifies critically reflective practice that enables us to draw upon multiple diverse studies to generate new knowledge about visualization in practice. Towards this secondary contribution we include, in Supplemental Materials[1], an *audit trail* [6, 34] of artifacts that show the evolution of our thinking and reasoning over the two year collaboration.

In the remainder of this paper, we first summarize the background and related work to visualization creativity workshops in Sec. 2. Next, we describe our workshop experience in Sec. 3 and the analysis methods that we used to generate the framework in Sec. 4. Then, we introduce the framework in Sec. 5 – 9. After that, we discuss implications and limitations of the work in Sec. 10. Finally, we identify areas for future work in Sec. 11.

2 Background and Related Work

In this section, we provide a background on visualization creativity workshops in three parts. First, we define creativity and creativity workshops. Second, we summarize the use of creativity workshops in two domains that are similar to applied visualization. Third, we describe the recent use of visualization creativity workshops.

2.1 Creativity Workshops

Creativity is an overloaded term. It can be defined as the generation of new and useful ideas [43], which often result from focused work and series of interconnected mini-insights [59]. It can be defined as a process in which a broad space of ideas are considered before selecting the more promising ones [37]. It can also be defined in the context of a group, where it emerges from open communication and cross-pollination of ideas [58].

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[1] http://vdl.sci.utah.edu/VisualizationCreativityWorkshops/

Creativity workshops are workshops that deliberately and explicitly foster creativity in all of its meanings [53]. Whether such workshops actually enhance creativity is the subject of nuanced debate [50]. Regardless, in this paper, we focus on creativity workshops as an effective method for visualization design.

2.2 Origins of Visualization Creativity Workshops

The origins of visualization creativity workshops can be traced to work in software requirements engineering and creative problem solving.

Visualization creativity workshops are based on creativity workshops for software requirements engineering [15]. In software requirements workshops, researchers deliberately and explicitly foster creativity while guiding 18 - 24 participants through 0.5 - 2 days of structured methods, generating hundreds of ideas for software systems [29] that can be used in requirements engineering processes [28] and agile development practices [22]. There are many documented uses of software requirements creativity workshops [27, 40, 41, 42], but this work reports on the experience of using workshops instead of providing guidance about how to use workshops.

Visualization creativity workshops are also based on workshops for creative problem solving, which are often used in a business setting [52]. Although many frameworks have been proposed for creative problem solving workshops (e.g., Creative Problem Solving [8], Lateral Thinking [10], and Synectics [17]), there is no conclusive evidence that any one framework is more effective than the others [50, 59]. Furthermore, surveys of creativity workshop frameworks reveal that they share underlying principles that include encouraging open communication, promoting trust and risk taking, providing time for focused work, fostering divergent and convergent thinking, supporting iteration of ideas, emphasizing problem finding and solving, and eliciting group creativity [50]. In this paper, we propose ways to adapt and adopt these principles in the context of visualization.

2.3 Visualization Creativity Workshops

In the previous subsection we described the use of creativity workshops outside of visualization, but, for brevity, we henceforth use the term **creativity workshop** to refer specifically to creativity workshops in the context of visualization. To our knowledge, this paper is the first meta-analysis of creativity workshops. Here, we summarize projects that report on their use.

Three related projects have used a series of creativity workshops in applied collaborations. Dykes et al. [14] described three creativity workshop-like imagination exercises to explore opportunities for enhancing map legends with visualization. Goodwin et al. [15] built on these experiences, reporting on their collaboration with energy analysts that used a series of creativity workshops to discover opportunities for visualization, to develop and iterate on prototypes, and to evaluate the resulting visualizations. Walker et al. [68] also applied three creativity workshops in a collaboration with defense analysts to understand needs, create designs, and evaluate prototypes. All three projects report on their experiences using workshops, but do not provide instructions about how others could use workshops in the future.

Recently, three additional projects used a single creativity workshop to jump-start applied collaborations. First, Kerzner et al. [31] used a full-day workshop to understand the analysis needs of neuroscientists. Second, Goodwin et al. [16] applied a full-day workshop to explore visualization opportunities in the field of constraint programming. Third, Nobre et al. [51] used a half-day workshop to elicit requirements from analysts working with psychiatric data. These three projects showed that a single creativity workshop can help researchers to rapidly understand domain problems and explore visualization opportunities. Yet, none of these project provide guidance for using creativity workshops in future projects.

We (the authors) have been involved with *every* creativity workshop described in this subsection. In this paper, we describe why and how to use such workshops — including guidelines for future workshops, mistakes that we have made in our workshops, and lessons learned from using a workshop in a collaboration that ultimately failed [30].

3 Creativity Workshop Experience and Terminology

Our experience includes 17 workshops in 10 projects relevant to applied visualization. In 3 projects (10 workshops), we used a series of workshops to explore opportunities for and create prototypes of visualizations [14, 15, 68]. In 3 projects (3 workshops), we used one workshop to understand analysis needs and characterize domain problems [16, 31, 51]. Similarly, in 2 projects (2 workshops) we used one workshop to explore opportunities for funded collaboration [30, 35]. Finally, in 2 projects (2 workshops), we used participatory and creative workshops that explored visualization designs with a variety of domain specialists at IEEE VIS [54, 55].

It is challenging to analyze diverse workshops because the criteria for workshop success depends on its intended outcome. We therefore narrowed our analysis to creativity workshops used in the early, formative stages of applied work or as the first in a series of workshops. These workshops typically focus on eliciting requirements for visualization software from collaborators. They support the *understand* and *ideate* design activities of the design activity framework [45] or fulfill the *winnow*, *cast*, and *discover* stages of the design study methodology's nine-stage framework [61].

Focused on workshops in the early stages of applied work, our experience includes 8 projects and 8 workshops, summarized in Tab. 1 and Tab. 2. Because we analyzed more data than appeared in the resulting publications, including artifacts and experiential knowledge, we refer to projects and their workshops by unique identifiers, e.g., [P1] refers to our collaboration with cartographers. In projects where we used more than one workshop [P1 – P3], the identifier corresponds to the *first* workshop in the series of workshops unless otherwise specified. (Although our analysis focused on 8 workshops, our experience with all 17 workshops has contributed to our framework.)

Within the narrow scope of our analysis, the projects are quite diverse. The project goals ranged from documenting and exploring the potential of visualization within a domain [P1 – P3], to creating tools that support existing analysis needs [P4 – P6], to exploring the possibilities for funded collaboration [P7, P8]. The projects were completed during the past 10 years on 3 continents. They were conducted by researchers at City, University of London [P1 – P3], the University of Utah [P4, P6 – P8], and Monash University [P5]. Details about the workshops used in each project are described throughout this paper and its Supplemental Material.

To describe our experience, we propose terminology for the role of researchers involved in each project. The **primary researcher** is responsible for deciding to use a creativity workshop, executing the workshop, and integrating the workshop results into a collaboration through analysis and action. Alternatively, **supporting researchers** assist in the workshop process, providing guidance and support to the primary researcher. We have been involved with projects as both primary and supporting researchers.

We also propose terminology to describe creativity workshops. Workshops are composed of **methods**, specific repeatable activities [9]. The methods are designed around a **theme** that identifies the workshop's central topic or purpose [5]. The **facilitators** plan and guide the workshop and the **participants** carry out the workshop methods. Typically the facilitators are visualization researchers and participants are domain collaborators. But, visualization researchers can participate [P1, P3] and domain collaborators can facilitate [P5, P8]. This vocabulary permeates the framework and emerged from our reflective research process.

4 Research Process

The contributions in this paper arise from *reflection* — the analysis of experiences to generate insights [2]. More specifically, we applied a methodology of *critically reflective practice* [4], summarized by Thompson [65] as *"synthesizing experience, reflection, self-awareness and critical thinking to modify or change approaches to practice"* to make sense of our experiential knowledge while intertwining reflection with action.

We analyzed our collective experience and our workshop data, which consisted of documentation, artifacts, participant feedback, and

ID	Year	Domain	Summary	Workshops	Result	Prim.	Supp.	Ref.
P1	2009	Cartography	*"Reimagining the legend as an exploratory visualization interface"*	3	Paper	JD	*	[14]
P2	2012	Smart Homes	Deliver insights into the role of smart homes and new business potential	4	Paper	SG	JD,SJ,*	[15]
P3	2012	Human terrain	*"develop [visualization] techniques that are meaningful in HTA"*	3	Paper	JD	*	[68]
P4	2015	Neuroscience	Explore problem-driven multivariate graph visualization	1	Paper	EK	MM, *	[31]
P5	2015	Constraint prog.	Design performance profiling methods for constraint programmers	1	Paper	SG	*	[16]
P6	2017	Psychiatry	Support visual analysis of determining or associated factors of suicide	1	Paper	*	EK,*	[51]
P7	2017	Genealogy	Discover opportunities to support visual genealogy analysis	1	—	*	EK,MM,*	[30]
P8	2017	Biology	Support phylogenetic analysis with visualization software	1	In-progress	*	EK,MM,*	[35]

Table 1. Summary of the projects in which we have used creativity workshops: 6 resulted in publications at major visualization venues [P1 —P6], we consider 1 to be a failure [P7], and 1 is in-progress [P8]. We characterize our involvement in these projects as either the primary researcher or as supporting researchers. The * represents colleagues who were involved in each project but not co-authors of this paper.

ID	Theme	Facil.	Partic.	Hrs
P1	Explore possibilities for enhancing legends with visualizations	1v	3v / 5c	6
P2	Identify future opportunities for utilising smart home data/technologies	2v / 1p	0v / 5c	6
P3	Identify novel visual approaches most suitable for HTA	1v / 1p	7v / 6c	9
P4	Explore shared user needs for visualization in retinal connectomics	4v	0v / 9c	7
P5	Identify analysis and vis. opportunities for improved profiling of cons. prog.	2v / 1c	0v / 10c	7
P6	Understand the main tasks of psychiatric researchers	2v	1v / 6c	3
P7	Explore opportunities for a design study with genealogists	1v	3v / 7c	3
P8	Explore opportunities for funded collaboration between vis. and bio.	1v / 1c	2v / 12c	7x2

Table 2. Summary of a workshop used in each project. We describe workshops by their theme, a concise statement the topics explored. We characterize workshop stakeholders as facilitators or participants categorized by their affiliation as (v)isualization researchers, (c)ollaborators, or (p)rofessional facilitators. Our workshops included 5 – 14 participants and ranged in length from half a day to 2 days.

research outputs. The analysis methods that we used can be described through the metaphorical lenses of critically reflective practice:

- the lens of our collective experience — we explored and articulated our experiential knowledge through interviews, discussions, card sorting, affinity diagramming, observation listing, and observations-to-insights [32]. We codified our experience, individually and collectively, in both written and diagram form. We iteratively and critically examined our ideas in light of workshop documentation and artifacts.
- the lens of existing theory — we grounded our analysis and resulting framework in the literature of creativity and workshops [1, 8, 10, 17, 19, 47, 50, 53, 58, 59, 62] as well as visualization design theory [45, 48, 60, 66].
- the lens of our learners (i.e., readers) — in addition to intertwining our analysis with the use of additional workshops, we shared early drafts of our framework with visualization researchers, both novice and veterans, who were interested in using workshops in their own projects. We used their feedback to hone the framework, making it more actionable and consistent.

Our reflective analysis, conducted over two years, was messy and iterative. It included periods of focused analysis and writing, followed by reflection on what we had written, which spurred additional analysis and rewriting. Throughout this time, we generated diverse artifacts, including models for thinking about how to use creativity workshops, written reflections on which methods were valuable to workshop success, and collaborative writing about the value of workshops. This paper's Supplemental Material contains a timeline of significant events in our reflective analysis and 30 supporting documents that show how our ideas evolved into the following framework.

5 Fundamentals of the Framework

In this section, we explicate the framework's purpose, propose a set of factors that contribute to successful workshops, and introduce the workshop process model and workshop structure.

5.1 Purpose of the Framework

We created the framework to describe how and why to use creativity workshops in applied visualization. We use the term *framework* because what we have created provides an interpretive understanding and approach to practice instead of causal or predictive knowledge [26]. In other words, we base the framework on careful analysis of our experience in the context of existing creativity, visualization, and workshop theory. But, we recognize that it is hard to describe and predict the actions and thoughts of people involved with workshops.

We intend for the framework to be a thinking tool for researchers to navigate the process of planning, running, and analyzing a workshop. It cannot resolve every question about workshops because the answers will vary by context. Instead, the framework proposes ideas that we consider particularly important for future workshops. It should be complemented by existing resources about how to use workshops [5, 18, 19], as well as local experience, preference, and context.

The framework assumes that researchers have decided to use a creativity workshop. This decision could be motivated by many reasons, including to sample problems faced by analysts in different organizations [P5], to explore shared needs from seemingly diverse analysts [P4, P5, P6], to make use of limited meeting time with groups of collaborators [P1, P3, P8], and to identify surrogate data if real data are not available [P3]. Our analysis across a wide range of contexts provides evidence that workshops are a valuable method in a variety of applications, regardless of the domain collaborators. However, we discuss cases where a workshop may not be appropriate in Sec. 10.

5.2 Tactics for Workshop Success

The definition of workshop success depends on the reason for running the workshop. But, reflecting on our experience and reviewing the relevant literature [50, 53, 58, 59, 62] reveals several key factors that influence the engagement and creativity of workshop participants: focusing on the `topic` of visualization, data and analysis, while fostering, maintaining, and potentially varying the levels of `agency`, `collegiality`, `trust`, `interest`, and `challenge` associated with each. We term these factors **`tactics` for workshop success**:

- (**`T`**)`opic` — the space of ideas relevant to data, visualization, and domain challenges in the context of the workshop theme;
- (**`A`**)`gency` — the sense of participant ownership in the workshop outcomes and the research project;
- (**`C`**)`ollegiality` — the degree to which open communication and collaboration are encouraged and occur;
- (**`T`**)`rust` – the confidence that participants have in each other, the workshop, the design process, and the researcher's expertise;
- (**`I`**)`interest` — the amount of attention, energy, and engagement to workshop methods;
- (**`C`**)`hallenge` — the barrier of entry to, and likelihood of success in, workshop methods;

The `tactics` are not independent, consistent, or measurable. The extent to which they are fostered depends upon the context in which

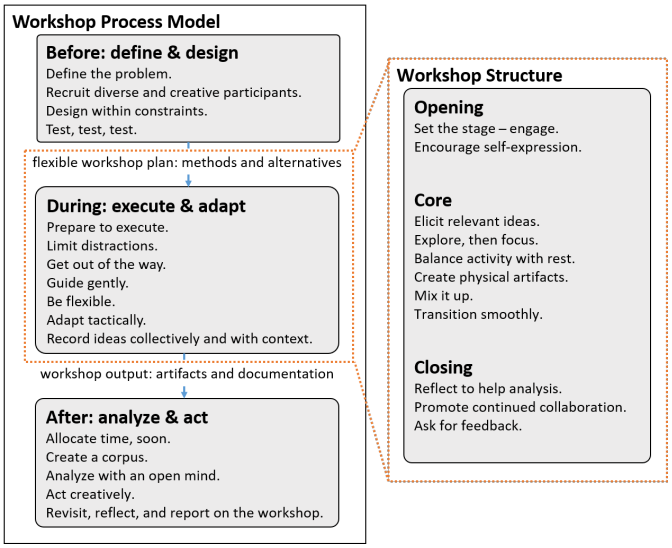

Fig. 1. The framework's two models are 1) a process model (left) that describes the common actions before, during, and after workshops; and 2) a structure that describes principles for methods used in the beginning, in the middle, and at the end of workshops. In these models, we propose 27 guidelines for future workshops, summarized here.

they are used, including various characteristics of the workshop group — often unknown in advance, although perhaps detectable by facilitators. Yet, maintaining appropriate levels `agency`, `interest`, and `trust` — while varying levels of `challenge` and approaching the `topic` from different perspectives — likely helps workshops to inspire and engage participants while creating useful output and establishing lasting rapport among researchers and their collaborators. Hence, we refer to the tactics while describing our experience throughout this paper.

5.3 Process Model and Structure

The framework proposes two models for describing how to use creativity workshops: a process model and a workshop structure. The models were adapted from the extensive literature that describes how to use workshops outside of visualization [5, 8, 10, 13, 18, 19, 53].

The process model (Fig. 1 (left)) consists of three stages that describe the actions of using workshops:

1. **Before: define & design.** Define the workshop's theme and design the workshop methods, creating a flexible workshop plan.
2. **During: execute & adapt.** Perform the workshop plan, adapting it to participants' reactions in light of the `tactics`, generating workshop output as a set of rich and descriptive artifacts and documentation.
3. **After: analyze & act.** Make sense of the workshop output and use it to influence the downstream design process.

Nested within the process is the workshop structure (Fig. 1 (right)) that identifies key aspects of the methods used in the beginning, middle, and end of workshops:

1. **Opening.** Establish shared context and `interest` while promoting `trust`, `agency`, and `collegiality`.
2. **Core.** Promote creative thinking about the `topic`, potentially varying `challenge` to maintain `interest`.
3. **Closing.** Provide time for reflection on the `topic` and promote continued `collegiality` in the collaboration.

The process model and structure are closely connected as shown by the orange box in Fig. 1, making it challenging to completely disentangle them. As part of the workshop process, we design and execute a workshop plan. This plan follows the workshop structure because it organizes methods into the opening, core, and closing. In other words, the process is about how we use a workshop; the structure is about how methods are organized within a workshop.

We use the process model and structure to organize the following four sections of this paper. Throughout these sections, we use paragraph-level headings to summarize 27 actionable guidelines for future workshops.

6 Before the Workshop: Define & Design

Creating an effective workshop is a design problem: there is no single correct workshop, the ideal workshop depends on its intended outcomes, and the space of possible workshops is practically infinite. Accordingly, workshop design is an iterative process of defining a problem, testing solutions, evaluating their effectiveness, and improving ideas. Here, we propose four guidelines — summarized in paragraph-level headings — for workshop design.

Define the problem. Just as design starts with defining a problem, creating a workshop starts with defining its purpose. We usually articulate the workshop purpose in a concise theme that describes the ideas that will be explored in the workshop.

An effective theme piques `interest` in the workshop among researchers and collaborators. Our themes have focused on specific domain challenges, such as *"enhancing legends with visualizations"* [P1], or stated specific goals such as to *"identify analysis and visualization opportunities for improved profiling of constraint programs"* [P5]. Our themes have also focused on broader topics, such as *"explore opportunities for a funded collaboration with phylogenetic analysts"* [P8]. All of our themes specified topics which we considered promising for visualization because they exhibited the appropriate *information location* and *task clarity* [61].

The theme is often iteratively improved as researchers establish a better understanding of domain challenges through user-centered design methods, including interviews and observations. Overall, the theme grounds the process of designing a workshop and can help to identify promising workshop participants.

Recruit diverse and creative participants. We recruit workshop participants who can bring relevant knowledge and diverse perspectives about domain challenges to the workshop. But, the participants can be constrained by the context of the collaboration. For example, we have been limited to recruiting participants from a small set of collaborators who were working with us [P3, P6].

In other cases, however, we have had a larger set of potential participants. In these cases, we consider participants based on their `interest` in the `topic`, openness to `challenge`, and potential `collegiality`. Examples of successful participants include a mix of frontline analysts, management, and support staff [P4]; practitioners, teachers, and students [P5]; or junior and senior analysts [P6]. We suggest recruiting participants who can attend the workshop in-person because remote participation through video conferencing software proved distracting [P8].

Surveys are one particularly effective method for recruiting participants. We have sent surveys to potential participants to gauge their interest in a workshop and ask about key domain challenges that could be addressed with visualization [P5].

The design study methodology's character roles [61] can be useful to select promising participants. A mix of *frontline analysts*, *gatekeepers*, and *translators* can bring diverse perspectives about the `topic`. *Fellow-tool builders* should be approached with caution since their perspectives may distract from the `topic`. The participants in our failed workshop [P7] were mostly fellow tool-builders, making it hard to find real domain challenges in the workshop output.

Design within constraints. Identifying details of the workshop early, and using them to constrain the workshop possibilities, can help in workshop design. Although it is impossible to list every detail to consider, the following questions have helped to constrain our workshop design:

- Who will use the workshop results? Identifying the primary researcher early in the process is critically important because they will be responsible for the workshop and ultimately use its results. In our failed workshop [P7], the primary researcher was not clearly defined and the results went unused.

- How many participants will be in the workshop? We have run workshops with 5 - 14 participants who are typically domain collaborators, but may also be visualization researchers.
- Who will help to facilitate the workshop? We have facilitated our workshops as the primary researcher with the assistance of supporting researchers or professional workshop facilitators. Domain collaborators can also be effective facilitators, especially if the domain vocabulary is complex and time is limited [P5, P8].
- How long will the workshop be? An effective workshop lasts about one working day. While we have experience with shorter [P6, P7] or longer workshops [P8], these either feel rushed or require too much time commitment from collaborators.
- Where will the workshop be run? Workshop literature expounds the importance of neutral, well-lit venues [8, 25], and although such venues can be successful [P2, P3], we have also had success with workshops in conference rooms at both our collaborators' and our own workplaces [P4 – P6].
- What are additional workshop constraints? Additional project characteristics may constrain the possibilities of our workshops. Examples from our experience include the inability of collaborators to share sensitive data with us [P3, P6], as well as the funding available for workshop materials.

The answers to these questions are mutually influential. For example, the number of participants influences what size room is necessary and where the workshop will be run. The answers usually emerge from an iterative design process.

Test, test, test. Piloting (i.e., testing) methods can ensure that the workshop will generate ideas relevant to the `topic` while maintaining appropriate levels of `interest` and `challenge`. We have piloted methods to evaluate how understandable they are [P2, P4], to test whether they create interesting results [P6, P8], and to find mistakes in their prompts [P2, P4, P6, P8].

We suggest that methods and workshops be piloted with the real prompts and materials. In one workshop [P4], we used methods that asked participants to record ideas on post-it notes. But, because we had bought post-it notes that were too large, participants wrote many ideas on each one, which made it hard to organize the ideas later in the workshop. In retrospect, this mistake could have been avoided by piloting the methods with the real materials.

We have also found it useful to pilot workshops with proxy participants, such as visualization researchers [P4] or domain collaborators [P8]. Involving collaborators helped us to improve our understanding of domain challenges, causing us to revisit decisions about the theme, participants, and methods.

7 Workshop Structure and Methods

This section describes guidelines for the methods used in the three workshop phases (described in Sec. 5) — the opening, core, and closing. It concludes with a summary of an example workshop and resources for additional workshop methods.

7.1 Workshop Opening

The workshop opening communicates the goals and guidelines for participants, but it can be more than that. It can foster `agency` by encouraging self-expression and idea generation. It can encourage `collegiality` and `trust` by by promoting open communication, acknowledging expertise and establishing a safe co-owned environment. It can also garner `interest` by showing that the workshop will be useful and fun. The following two guidelines contribute to an effective opening.

Set the stage — engage. Workshops typically open with a short introduction, reiterating the theme and establishing shared context for participants and facilitators. We have introduced workshops as *"guided activities that are meant to help us understand: what would you like to do with visualization?"*[P4]. We have also used graphics that summarize the goals of our project, potentially priming participants to engage with the `topic` of visualization [P3].

The opening can establish principles for creativity [8, 53], potentially fostering `trust` and `collegiality`. We used the following principles in one of our workshops [P2]: 1) all ideas are valid, express and record them; 2) let everyone have their say; 3) be supportive of others; 4) instead of criticizing, create additional ideas; 5) think 'possibility' – not implementation; 6) speak in headlines and follow with detail; and 7) switch off all electronic devices.

Introduction presentations should be kept short to maintain `interest`. Passive methods, such as lectures and presentations, can discourage participation at the outset. For example, we started one workshop [P8] with a presentation on the current state of analysis tools. This presentation encouraged participants to passively listen rather than actively explore, establishing a passive mindset that we had to overcome in subsequent workshop methods. An effective opening engages participants.

Encourage self-expression. We use methods that encourage self-expression to support interpersonal leveling and to act on the creativity principles — *all ideas are valid* and *be supportive of others*. Such interpersonal methods help to establish an atmosphere of `trust` and `collegiality` among participants and facilitators. They can also provide participants with a sense of `agency` [5].

We have used interpersonal methods that ask participants to sketch ideas rapidly while suspending judgment [55] (see Visual Improv. in Supplemental Material) or to introduce themselves through analogies as a potential primer for creativity (see Sec. 7.4). Overall, we use interpersonal methods in the opening to engage participants and facilitators, preparing them for the workshop core.

7.2 Workshop Core

In the workshop core, we harness the active and engaged mindset of participants by encouraging them to explore, create, and record ideas. The methods in the core potentially generate hundreds of post-it notes, sketches, and other artifacts. Analysis of our experience and relevant literature reveals six guidelines for an effective core.

Elicit relevant ideas. We refer to the set of all ideas being considered in the workshop as the ideaspace [1]. We select methods that focus the ideaspace on the `topic`— exploring the possibilities for visualization in a specific domain.

In line with existing visualization practices [61], we use methods that ask participants about their problems, not their envisioned solutions. Example prompts of effective methods include *"What would you like to see in your data?"* [P2], and *"What do you want to do with visualization software?"* [P5]. Responses to these prompts help us discover interesting visualization opportunities.

Explore, then focus. We organize the core to first generate ideas — using divergent methods that expand the ideaspace — and then to evaluate ideas — using convergent methods that winnow the ideaspace [53]. Using divergent methods early in the core allows us to consider many possibilities while also promoting `agency` and maintaining `interest`. Then, convergent methods can narrow the ideaspace to the more promising ideas.

Classifying methods as either divergent or convergent risks oversimplification as individual methods often include both divergent and convergent aspects. Consider our use of brainstorming [53] during one workshop [P1], we asked participants to record *"problems and successes associated with the current clients on [post-it] notes"* (divergent) and then to share the more interesting ideas (convergent). We classify this method as divergent because it creates ideas, despite the convergent discussion. In contrast, a convergent method may involve grouping post-it notes from previous methods. Overall, in line with existing workshop guidance [8, 10, 19, 53], we judge methods by their intended impact on the ideaspace and organize the core with phases of divergent and convergent methods.

Create physical artifacts. We select methods by how they encourage participants to write, to draw, or to otherwise externalize their ideas. Externalizing ideas has many benefits: 1) it creates artifacts for researchers to analyze after the workshop, 2) it aids creative thinking

because expressing an idea forces the creator to elaborate it [59], and 3) it promotes idea sharing, encouraging collegiality.

Post-it notes are a particularly useful form of externalization because they enable participants to group or rank ideas and potentially to discover emergent concepts in the ideaspace [13]. We have used post-it notes to externalize ideas in almost all of our workshops. When using post-it notes, we use their color to encode information such as the method or specific prompt that generated an idea, which can help with post-workshop analysis by establishing how ideas evolved and were valued throughout the workshop. Additional materials effective for externalizing ideas include handouts with structured prompts, butcher paper, and poster boards. Using whiteboards is tempting, but ideas are easily lost when boards are erased.

Balance activity with rest. Because continuously generating or discussing ideas can be tiring for participants, we structure workshop methods to provide a balance between activity and rest. Specifically, we incorporate passive methods that provide time for incubation, the conscious and unconscious combination of ideas [59].

Passive methods can include short breaks with food and coffee, informal discussions over meals, or methods where participants listen to presentations. When using methods that present ideas, asking participants to record their thoughts and reactions can promote interest and maintain a feeling of agency. We have typically used passive methods in full-day workshops [P2, P4, P5, P8], but we rely on breaks between methods for shorter workshops [P6].

Mix it up. We consider the relationships among methods to be important as we strive to balance exploration with focus and activity with rest, while also using many materials for externalizing ideas. Considering methods that vary these factors can provide different levels of challenge because, for example, methods that require drawing ideas may be more difficult than discussing ideas. Using a variety of methods may also maintain interest because participants may become bored if too much time is spent on a specific idea.

Transition smoothly. Despite using methods that vary on many attributes, we avoid potentially jarring transitions between methods to preserve participant interest. Convergent discussions can be used to conclude individual methods by highlighting the interesting, exciting, or influential ideas. These discussions can promote collegiality by encouraging communication of ideas, agency by validating participants' contributions, and interest in the ideas generated. Convergent discussions also highlight potentially important ideas for researchers to focus on after the workshop.

Convergent methods can also conclude the workshop core by grouping or ranking key ideas. We have used storyboarding to encourage the synthesis of ideas into a single narrative [P2, P4, P5]. We have also asked participants to rank ideas, providing cues for analyzing the workshop results [P3]. Convergent methods provide a sense of validation, potentially helping to build trust among researchers and collaborators as we transition to the closing.

7.3 Workshop Closing

The workshop closing sets the tone for continued collaboration in the project. It is an opportunity to promote collegiality by reflecting on the shared creative experience. The following three guidelines apply to effective closings.

Reflect to help analysis. We use discussions at the end of workshops to promote reflection, potentially providing validation to participants and generating information valuable for workshop analysis. Encouraging participants to reflect on how their ideas have evolved, such as by asking *"what do you know now that you did not know this morning?"* [P5] or *"what will you do differently tomorrow given what you have learned today?"* [P2] can provide validation for the time committed to the workshop. One participant, for example, reported *"I was surprised by how much overlap there was with the challenges I face in my own work and those faced by others"* [P5].

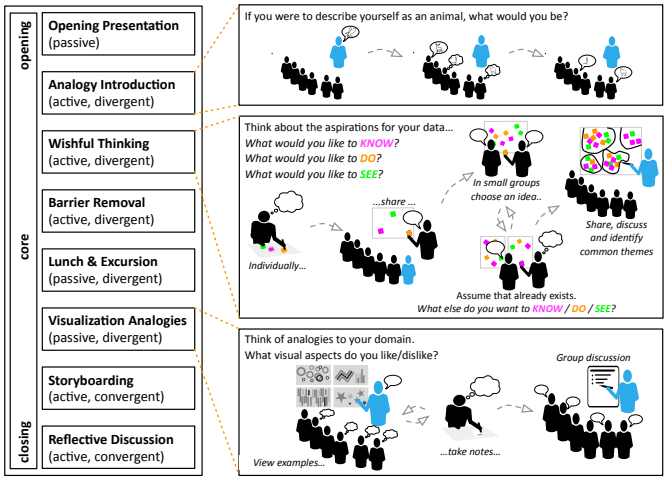

Fig. 2. The 8 methods of the full-day, example workshop (left) with the process of 3 methods summarized graphically (right). The workshop methods diverge to explore a broad ideaspace before they converge to the more promising ideas. Three of the methods are described in the text and the remainder are explained in the Supplemental Material. The methods can be summarized as: 1) the opening presentation establishes creativity principles; 2) an analogy introduction promotes interpersonal leveling; 3) wishful thinking elicits opportunities for visualization; 4) barrier removal explores those opportunities further; 5) lunch & excursion provides time for rest and incubation; 6) visualization analogies allows specification of requirements by example; 7) storyboarding summarizes key ideas in a graphic form; and 8) the reflective discussion highlights potentially interesting ideas for workshop analysis. This workshop plan is a starting point future workshops.

Promote continued creative collaboration. We also conclude the workshop by identifying the next steps of action, also potentially validating participant involvement. We can explain how the ideas will be used to move the collaboration forward, often for future design methods, as we describe in Sec. 9.

Ask for feedback. Asking participants for feedback about the workshop can provide valuable information. Although we have tried gathering feedback in a low-cost way that has been suggested for enabling post-workshop incubation — by handing out stamped postcards for participants to mail back to us — the number of responses was underwhelming [P2]. Recently, we have used online surveys to gather feedback on the effectiveness of the workshop, specific methods, and the facilitation style. The surveys provide important data about the effectiveness of workshop methods and the extent to which we addressed the tactics throughout our workshop. In our experience, e-mailing surveys to participants immediately after the workshop closing, so the surveys are available as participants leave the workshop, is an effective way to gather responses.

7.4 Example Workshop & Methods

The workshop structure provides scaffolding for thinking about how to design a workshop. An example workshop that follows this structure is shown in Fig. 2. We have used this workshop plan successfully in a number of projects [P2, P4, P5]. Here, we describe 3 methods of this workshop and the remaining 5 are in the Supplemental Material.

To explain the workshop methods we refer to their process — the steps of execution [1]. We note, however, this process description abstracts and simplifies the methods because, in practice, during their execution we adapt the process based on participant reactions and our own judgment of the tactics.

Analogy Introduction

We have used this active, interpersonal, and potentially divergent method in the workshop opening. A process of this method, shown

in Fig 2 (right, top), starts with a facilitator posing the analogy introduction prompt, e.g., *"if you were to describe yourself as an animal, what would you be?"* [P2]. The other facilitators and participants then respond to the prompt — expressing themselves creatively.

Because everyone must respond to the seemingly silly prompt, this method supports interpersonal leveling that helps to develop `trust` and `collegiality` among stakeholders. And, using analogy can prime participants to think creatively [17].

This method is short and seemingly simple, but participants report that it has a profound impact on creativity of the workshop because it promotes interpersonal leveling and creates a low bar for contributions, establishing that all ideas should be accepted and explored in the workshop [P4].

Wishful Thinking

We have used this divergent, active method early in the workshop core. It is based on creativity methods to generate aspirations [20] that we tailored to visualization by prompting participants with a domain scenario and asking the questions: *"What would you like to know? What would you like to do? What would you like to see?"*

One process of this method is shown in Fig. 2 (right, middle). First, we introduce the prompt and participants answer the know/see/do questions individually on post-it notes. Next, participants share ideas in a large group to encourage `collegiality` and cross-pollination of ideas. Then, participants form small groups and try to build on their responses by selecting interesting ideas, assuming that they have been completed, and responding to the know/see/do questions again — increasing the `challenge`. Finally, we lead a convergent discussion to highlight interesting ideas and to transition to the next method.

We encourage participants to record answers to the know/see/do questions on different color post-it notes because each prompt provides information useful at different points in the design process. Participants describe analysis tasks that they would like *to do* or envisaged insights they would like *to know*. Asking what participants would like *to see* is often more of a `challenge`, but ensures that a `topic` of visualization is established early.

We tailor the prompt to the workshop theme and project goals. For example, we asked energy analysts to think about long term goals for their project — *"aspirations for the SmartHome programme..."*. They generated forward-thinking ideas, such as to better understand the value of the data [P2]. In contrast, we asked neuroscientists about their current analysis needs — *"suppose you are analyzing a connectome..."*. They responded with shorter term ideas, such as to see neuron connectivity [P4].

Visualization Analogies

We have used this divergent, passive method later in the workshop core because it promotes incubation while allowing participants to specify visualization requirements by example. Similar to analogy-based creativity methods [17], we present a curated collection of visualizations and ask participants to individually record analogies to their domain and to specify aspects of the visualizations that they like or dislike.

One process of this method is shown in Fig. 2 (right, bottom). First, we provide participants with paper handouts that contain a representative image of each visualization. (We have encouraged participants to annotate the handouts, externalizing their ideas [P4, P5, P8].) Next, we present the curated visualizations on a projector and ask participants to think independently about how each visualization could apply to their domain and to record their ideas. Then, we discuss these visualizations and analogies in a large group.

We curate the example visualizations to increase `interest` and establish participants' `trust` in our visualization expertise. We have used visualizations that we created (to show authority and credibility); those that we did not create (for diversity and to show knowledge of the field); older examples (to show depth of knowledge); challenging examples (to stretch thinking); playful examples (to support engagement and creativity); closely related examples (to make analogies easy); and unrelated examples (to promote more challenging divergent thinking).

The discussions during this method have expanded the workshop idea space in surprising ways, such as *"what does it mean for legends to move?"* [P1], *"what does it mean for energy to flow?"* [P2], and *"what does it mean for neurons to rhyme?"* [P4]. And, although this method is primarily passive, participants have reported that it is engaging and inspiring to see the broad possibilities of visualization and think about how such visualizations apply to their domain.

Additional Resources

We introduce the example methods and example workshop as starting points for thinking about future workshops. The workshop design space is practically infinite and workshop design should be approached with creativity in mind.

To help researchers navigate the workshop design space, our Supplemental Material contains a list of 15 example workshop methods that we have used or would consider using in future workshops. For these methods, we describe their process, their influence on the workshop ideaspace — as divergent, convergent, or interpersonal — their level of activity — as active or passive — and their potential impact on `tactics` for successful workshops.

We have also found other resources particularly useful while designing workshops. These include books [8, 18, 19, 21, 32, 46], websites [39, 49], and research papers [44, 45, 56]. Although the methods in these resources target a range of domains outside of visualization, we typically adapt the methods to promote engagement with the `topic` of data, visualization, or analysis questions.

8 During The Workshop: Execute & Adapt

If planning a workshop is like choreography, this section is about the performance. Here, we propose six guidelines for effectively executing workshops while adapting them to the reactions of participants.

Prepare to execute. We prepare to execute the workshop by resolving many details, such as inviting participants, reserving the venue, ordering snacks for breaks, making arrangements for lunch, etc. Brooks-Harris and Stock-Ward [5] summarize many practical details that should be considered in preparing for execution.

We prepare ourselves by reviewing principles of effective facilitation, such as acting professional, demonstrating acceptance, providing encouragement, and using humor [5, 8, 18, 19, 64]. We also assess our knowledge of the domain because, as facilitators, we will need to lead discussions about it. Effectively leading discussions can increase `collegiality` and `trust` between participants and facilitators as participants can feel that their ideas are valued and understood. In cases where we lacked domain knowledge, we recruited domain collaborators to help facilitate the workshop [P5, P8].

We also prepare the venue by checking that it has the necessary supplies, such as a high quality projector, an Internet connection (if needed), and ample space for group activity. Within the venue, we arrange the furniture to promote a feeling of co-ownership and to encourage `agency`— a semi-circle seating arrangement works well for this [67]. A mistake in one of our workshops was to have a facilitator using a podium, which implied a hierarchy between facilitators and participants, hindering `collegiality` [54].

Limit distractions. Workshops provide a time to step away from normal responsibilities and to focus on the `topic`. Accordingly, participants and facilitators should be focused on the workshop without distractions, such as leaving for a meeting.

Communicating with people outside of the workshop — e.g., through e-mail — commonly distracts participants and facilitators. It should be discouraged in the workshop opening (e.g., *switch off all electronic devices*). Principles in the workshop opening, however, should be justified to participants. Also, facilitators should lead by example at the risk of eroding `trust` and `collegiality`.

Get out of the way. After the workshop opening establishes a creative atmosphere and fosters engagement, participants commonly take initiative in completing the workshop methods. Hence, we use the word *facilitator* to describe the individuals guiding the workshop because their role is to *facilitate* the exploration of ideas as opposed to

lead or *command* the participants. To an extent, facilitating a workshop is like conducting an interview because we should stay quiet and try to keep the participants talking or generating ideas.

Guide gently. It is, however, sometimes necessary to redirect the participants in order to stay focused on the `topic`. Conversations that deviate from the day's focus should be redirected. In one workshop [P4], participants were allowed to discuss ideas more freely and they reported in feedback that *"we had a tendency to get distracted [during discussions]."* In a later workshop [P8], we more confidently guided discussions, and participants reported *"we were guided and kept from going too far off track ... this was very effective."*.

However, guiding participants requires judgment to determine whether a conversation is likely to be fruitful. It also requires us to be sensitive to the `tactics`— e.g., how would redirecting this conversation influence `collegiality` or `agency`? Redirection can be jolting and can contradict some of the agreed guidelines (e.g., *"all ideas are valid!"*). We may prepare participants for redirection with another guideline during the workshop opening: *"facilitators may keep you on track gently, so please be sensitive to their guidance."*

Be flexible. As we guide participants to stay on topic, it is important to be flexible in facilitation. For example, we may spend more time than initially planned on methods that are generating interesting ideas. Alternatively, we may cut short the methods that bore participants. We may also improvise methods on-the-fly. In one of our workshops [P3], the participants proposed a method that they thought would be more useful than what we had planned. Adapting the workshop to perform this method reinforced the feeling of `agency` and maintained `interest` while creating useful and interesting ideas.

Adapt tactically. As we guide the workshop, we interpret group dynamics and adapt methods to the changing situation. We can be forced to adapt for many reasons, such as a failing method (*nobody feels like an animal this morning*; *post-its don't stick*), a loss of `interest` (*there is no energy*; *the room is too hot*; *we had a tough away day yesterday*) a lack of `agency` (*some participants dominate some tasks*); or an equipment failure (*projector does not work*; *no WiFi connection to present online demos*). Designing the workshop with alternative methods in mind — perhaps with varying degrees of `challenge`— can ensure that workshop time is used effectively.

Record ideas collectively and with context. Remember: conversations are ephemeral and anything not written down will likely be forgotten. We therefore encourage facilitators and participants to document ideas with context for later analysis. Selecting methods to create physical artifacts can help with recording ideas. As described in Sec. 7, externalizing ideas on post-it notes and structured prompts has been effective in our workshops.

We are uncertain about the use of audio recording to capture workshop ideas. Although it can be useful for shorter workshops [P6], it can require tremendous time to transcribe before analysis [36]. Also, recording audio effectively can be challenging as participants move around during the methods.

It can be useful to ensure that facilitators know that they are expected to help document ideas. A pilot workshop can help with this. In at least one of our projects [P5], a pilot workshop may have reduced the note taking pressure on the primary researcher during execution.

9 After the Workshop: Analyze & Act

After the workshop, we analyze its output and use the results of that analysis to influence the on-going collaboration. Here, we describe five guidelines for this analysis and action.

Allocate time for analysis. Soon. Effective workshops generate rich and inspiring artifacts that can include hundreds of post-it notes, posters, sketches, and other documents. Making sense of this output is labor intensive, often requiring more time than the workshop itself. Thus, it is important that we allocate time for analysis, particularly within a day of the workshop, so that we can analyze output while ideas are fresh in our memory.

Create a corpus. We usually start analysis by creating a digital corpus of the workshop output. We type or photograph the artifacts, organizing ideas into digital documents or spreadsheets. Through this process, we become familiar with key ideas contained in the artifacts. The corpus also preserves and organizes the artifacts, potentially allowing us to enlist diverse stakeholders — such as facilitators and collaborators — in analysis. This can help in clarifying ambiguous ideas or adding context to seemingly incomplete ideas.

Analyze with an open mind. Because the ideas in the workshop output will vary among projects, there are many ways to analyze this corpus of artifacts. We have used qualitative analysis methods — open coding, mindmapping, and other less formal processes — to group artifacts into common themes or tasks [P2, P4 – P7]. Quantitative analysis methods should be approached with caution as the frequency of an idea provides little information about its potential importance.

We have ranked the themes and tasks that we discovered in analysis according to various criteria, including novelty, ease of development, potential impact on the domain, and relevance to the project [P2, P4–P6]. In other cases [P1, P3], workshop methods generated specific requirements, tasks, or scenarios that could be edited for clarity and directly integrated into the design process.

We encourage that analysis be approached with an open mind because there are likely many ways to make sense of the workshop data that we have not yet considered.

Act creatively. Similarly, there are many ways to act on knowledge gained from the workshop. We have run additional workshops that explored the possibilities for visualization design [P1, P2]. We have applied traditional user-centered design methods, such as interviews and contextual inquiry, to better understand collaborator's tasks [P4]. We have created prototypes of varying fidelity, from sketches to functioning software [P4, P5, P6]. And, we have identified key aims in proposals for funded collaboration [P8]. In all of these cases, the knowledge gained from workshops profoundly influenced the direction of our collaboration.

Revisit, reflect, and report on the workshop. The workshop output is a trove of information that can be revisited throughout (and even beyond) the project. It can be used to document the evolution of ideas that occurs throughout applied collaborations. It can also be used to evaluate and validate design decisions in resulting publications by demonstrating that any resulting software fulfills analysis needs identified by the workshop data. In our experience of reflecting on the outputs from our own workshops during the development of the ideas in this paper, we also found new insights that we had not seen previously – we believe that revisiting workshop output repeatedly throughout a project could continually inspire new ideas and insights.

We encourage researchers to reflect and report on their experiences using creativity workshops, the ways in which workshops influence collaborations, and ideas for future workshops. We hope that this framework is a starting point for research into these topics.

10 Discussion

In this section, we reflect on the role of creativity workshops in applied visualization, then we reflect on the methodology that we used to generate the framework.

10.1 Why Creativity Workshops?

Although the results of research projects are likely to be creative if preceded by a creativity workshop [15], arguably all applied visualization research is creative as it involves generating new and useful ideas. Thus, we think it likely that creativity workshops are an effective, efficient, and insightful method, appropriate for almost any applied visualization research project.

Workshops provide time for focused discussions and they produce tremendous amounts of artifacts and data that capture the domain challenges and opportunities for visualization. For these reasons, we speculate that workshops have saved us significant amounts of time pursuing problem characterizations when compared to using traditional

design study approaches that involve one-on-one interviews and observations. What may have taken several months we accomplished with several days of workshop preparation, execution, and analysis. One reason for this is, due to their structured nature, workshops effectively use the limited time and energy of collaborators, as noted by one participant [P8]: *"the structured format helped us to keep on-topic and to use the short time wisely. It also helped us rapidly focus on what were the most critical needs going forward. At first I was a little hesitant, but it was spot-on and wise to implement."*

The characteristics engendered by a creativity workshop — `trust`, `collegiality`, `interest`— are critically important to successful collaborations [60, 61, 63]. Workshops provide a forum that can allow all project stakeholders to contribute to the design requirements by using methods that explicitly encourage `trust` among stakeholders, while promoting individual `agency`. We speculate that in our own projects, using workshops early in the design process has led to visualization tools that generalize more broadly due to the diversity of perspectives and needs that the workshops highlight and support.

The interpersonal benefits also extend beyond the workshop experience. For example, in one project [P4], after a successful workshop, members of an academic laboratory were more willing to meet with us regularly and provide us with help accessing and parsing their data. We believe that this shift in accessibility was a direct result of the workshop experience and would not have happened using more traditional collaboration techniques [69].

In short, we argue that workshops are a valuable method for facilitating and fostering most applied research collaborations. Our experiences across diverse domains — from cartography to neuroscience — and with diverse collaborators — from defense analysts to product developers — suggest that workshops can be adopted and adapted for specific domain challenges and collaborations.

We recognize, however, that workshops may not be appropriate in some scenarios. Because using workshops require visualization researchers to ask interesting questions and potentially lead discussions about their collaborator's domain, we caution the use of workshops as the first method in a project. More traditional user-centered approaches should be used to learn domain vocabulary and explore the feasibility of collaboration. In our failed workshop [P7], we did not know enough about the domain to effectively craft workshop methods. Also, our collaborators were too busy to meet with us before the workshop, which, in retrospect, should have been a warning about the nature of the project. Accordingly, we recommend researchers evaluate the preconditions of design studies [61] in projects where they are considering workshops.

10.2 Why Critically Reflective Practice?

Throughout this project, we wrestled with a fundamental question: how can we rigorously learn from our diverse collective experience? We initially examined measurable attributes of our workshops, such as their length, number of participants, and ideas generated. But this analysis fell short of establishing useful knowledge because, for example, it is nearly impossible to measure the usefulness of generated ideas or the influence of a workshop on a collaboration.

We also considered qualitative research methodologies such as grounded theory [7], and methods such as thematic analysis [3]. Such methodologies and methods, however, focus on extracting meaning from externalized data, and we found that the most meaningful and useful information about workshops resided in our collective, experiential knowledge, which was not yet codified or described.

We therefore abandoned analysis methods that ignore (or seek to suppress) the role of experience in knowledge generation. We found critically reflective practice to be an appropriate approach, providing a methodology to learn from the analysis of experience, documentation, and existing theory, while allowing for the flexible use of additional analysis methods [4, 65]. Due to the nature of reflection, however, the framework is not exhaustive, predictive, or objective. Nevertheless, the framework is consistent with our experience, grounded in existing theory, and, we believe, useful for future visualization research.

We attribute our successful use of critically reflective practice in part to the rich documentation that we collected during the projects that used creativity workshops. Through our reflection on this documentation in conjunction with our experiential knowledge, we created, curated, and analyzed more than 50 reflective artifacts that reveal significant events in our collaboration and the evolution of our thinking. These artifacts include comparative analysis of our workshops, presentations outlining the framework, early written drafts of our framework, and structured written reflection to elicit ideas from all of this paper's co-authors. The artifacts show how our collaboration started with a seemingly simple question about 2 of our workshops — what could we do better next time? — and evolved over 2 years into the framework presented in this paper. Each time we revisited these artifacts they challenged our thinking as our ideas evolved, exemplifying the *critical* nature of critically reflective practice. Upon reflection, we should have done this revisiting more often, and in future projects plan to do so on a regular basis.

We provide an audit trail of these artifacts in the Supplemental Material, both as validation of our analysis process and for transferability of many of the ideas contained therein. The audit trail summarizes and includes 30 of the reflective artifacts, culled from the original set to protect the privacy of internal discussions and confidential materials from our domain collaborators. In future reflective projects we plan to establish guidelines that encourage transparency of reflective artifacts through mechanisms to flag documents as on- or off-the-record. Because our research and meta-analysis would have been impossible without well-preserved documentation, we hope that the audit trail inspires future thinking on how to document and preserve the decisions in visualization collaborations. We tentatively put forth both the audit trail and our successful use of critically reflective practice as examples of these methods in practice.

11 Conclusion and Future Work

This paper contributes a framework for using creativity workshops in the early, formative stages of applied visualization research. The framework consists of two models for creativity workshops — a process model and a workshop structure. The framework also includes 27 actionable guidelines for future workshops, a validated example workshop, and 15 additional example workshop methods. We support the framework with a timeline of our analysis and an audit trail documenting how we developed the framework during a two year reflective collaboration. We hope that this framework inspires others to use and report on creativity workshops in applied visualization research.

One interesting area for future work is investigating the role of data in creativity workshops. Applied visualization research stresses the importance of using real data early in collaborative projects [36, 61]. However, our creativity workshops tend to focus participants on their perceptions of data rather than using real data because working with data is time consuming and unpredictable. In some projects, we incorporated data into the design process by using a series of workshops spaced over weeks or months, providing time for developers to design prototypes between workshops [P1 – P3]. But, this development between workshops was expensive in terms of time and effort. Technologies and approaches that may provide quick and reliable ways of using data in workshops are emerging, such as high-level visualization design tools, declarative visualization languages, and constructive visualization [24]. We also see opportunities for discovering more about the balance between data, creativity, and the `tactics` that are central to successful workshops.

Additionally, in this paper we focused on visualization creativity workshops used in the early stages of applied work. We would like to explore how the framework could be extended for workshops that correspond to other stages of applied work — including creativity workshops to create prototypes, to evaluate prototypes, or to deploy completed systems. We see this framework as the first step toward understanding how and why to use creativity workshops in applied visualization research.

REFERENCES

[1] M. M. Biskjaer, P. Dalsgaard, and K. Halskov. Understanding creativity methods in design. In *ACM SIGCHI Conference on Designing Interactive Systems*, 2017.

[2] D. Boud, R. Keogh, and D. Walker. *Reflection: turning experience into learning*. Routledge Taylor and Francis Group, London, UK, 1985.

[3] V. Braun and V. Clarke. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 2006.

[4] S. Brookfield. Critically reflective practice. *Journal of Continuing Education in the Health Professions*, 18(4), 1998.

[5] J. E. Brooks-Harris and S. R. Stock-Ward. *Workshops: designing and facilitating experiential learning*. SAGE Publications, Inc, Thousand Oaks, CA, 1999.

[6] M. Carcary. The research audit trail-enhancing trustworthiness in qualitative inquiry. *The Electronic Journal of Business Research Methods*, 7(1), 2009.

[7] J. Corbin and A. Strauss. Grounded theory research: procedures, canons, and evaluative critera. *Qualitative Sociology*, 13(1), 1990.

[8] Creative Education Foundation. *Creative problem solving resource guide*. Creative Education Foundation, Scituate, MA, 2015.

[9] M. Crotty. *The Foundations of Social Research*. SAGE Publications, Inc, London, UK, 1998.

[10] E. de Bono. *Lateral thinking for management*. Pelican Books, Middlesex, England, 1983.

[11] G. Dove. *CoDesign with data*. PhD thesis, City University London, 2015.

[12] G. Dove and S. Jones. Using data to stimulate creative thinking in the design of new products and services. *Proc. Conference on Designing Interactive Systems*, 2014.

[13] G. Dove, S. Julie, M. Mose, and N. Brodersen. Grouping notes through nodes: the functions of post-it notes in design team cognition. *Design Thinking Research Symposium*, 2016.

[14] J. Dykes, J. Wood, and A. Slingsby. Rethinking map legends with visualization. *IEEE Transactions on Visualization and Computer Graphics*, 16(6), 2010.

[15] S. Goodwin, J. Dykes, S. Jones, I. Dillingham, G. Dove, D. Allison, A. Kachkaev, A. Slingsby, and J. Wood. Creative user-centered design for energy analysts and modelers. *IEEE Transactions on Visualization and Computer Graphics*, 19(12), 2013.

[16] S. Goodwin, C. Mears, T. Dwyer, M. Garcia de la Banda, G. Tack, and M. Wallace. What do constraint programming users want to see? Eexploring the role of visualisation in profiling of models and search. *IEEE Transactions on Visualization and Computer Graphics*, 23(1), 2016.

[17] J. Gordon, William. *Synectics - the developmnent of creative capacity*. Harper and Row, New York, NY, USA, 1961.

[18] D. Gray, J. Macanufo, and S. Brown. *Gamestorming: a playbook for innovators, rulebreakers, and changemakers*. O'Reilly Media, 2010.

[19] P. Hamilton. *The workshop book: how to design and lead succesful workshops*. FT Press, Upper Saddle River, NJ, USA, 2016.

[20] M. J. Hicks. *Problem Solving and Decision Making: Hard, Soft, and Creative Approaches*. Thomson Learning, London, UK, 2004.

[21] L. Hohmann. *Innovation Games: Creating Breakthrough Products Through Collaborative Play*. Addison-Wesley, Boston, MA, 2007.

[22] B. Hollis and N. Maiden. Extending agile processes with creativity techniques. *IEEE Software*, 30(5), 2013.

[23] J. Horkoff, N. Maiden, and J. Lockerbie. Creativity and goal modeling for software requirements engineering. In *ACM Conference on Creativity and Cognition*, 2015.

[24] S. Huron, S. Carpendale, A. Thudt, A. Tang, and M. Mauerer. Constructive Visualization. In *ACM SIGCHI Conference on Designing Interactive Systems*, 2014.

[25] S. Isaksen, K. Dorval, and D. J. Treffinger. *Creative approahces to problem solving*. Kendall/Hunt, Dubuque, Iowa, 2000.

[26] Y. Jabareen. Building a conceptual framework: philosophy, definitions, and procedure. *The International Journal of Qualitative Methods*, 8(4), 2008.

[27] S. Jones, P. Lynch, N. Maiden, and S. Lindstaedt. Use and influence of creative ideas and requirements for a work-integrated learning system. In *IEEE International Requirements Engineering Conference, RE'08*, 2008.

[28] S. Jones and N. Maiden. RESCUE: An integrated method for specifying requirements for complex socio-technical systems. In J. L. Mate and A. Silva, editors, *Requirements Engineering for Sociotechnical Systems*. Information Resources Press, Arlington, VA, 2005.

[29] S. Jones, N. Maiden, and K. Karlsen. Creativity in the specification of large-scale socio-technical systems. In *Conference on Creative Inventions, Innovations and Everyday Designs in HCI*, 2007.

[30] E. Kerzner, A. Lex, and M. Meyer. Utah population database workshop, 2017.

[31] E. Kerzner, A. Lex, T. Urness, C. L. Sigulinsky, B. W. Jones, R. E. Marc, and M. Meyer. Graffinity: visualizing connectivity in large graphs. *Computer Graphics Forum*, 34(3), 2017.

[32] V. Kumar. *101 design methods: a structured approach to driving innovation in your organization*. Wiley, 2012.

[33] H. Lam, E. Bertini, P. Isenberg, and C. Plaisant. Evaluation To cite this version : Seven Guiding Scenarios for Information Visualization Evaluation. *IEEE Transactions on Visualization and Computer Graphics*, 18(9), 2012.

[34] Y. S. Lincoln and E. Guba. *Naturalistic Inquiry*. SAGE Publications, Inc, Thousand Oaks, CA, 1985.

[35] C. Lisle, E. Kerzner, A. Lex, and M. Meyer. Arbor Summit Workshop, 2017.

[36] D. Lloyd and J. Dykes. Human-centered approaches in geovisualization design: investigating multiple methods through a long-term case study. *IEEE Transactions on Visualization and Computer Graphics*, 17(12), 2011.

[37] J. Löwgren. Applying design methodology to software development. In *ACM SIGCHI Conference on Designing Interactive Systems*, 1995.

[38] N. Maiden, S. Jones, K. Karlsen, R. Neill, K. Zachos, and A. Milne. Requirements engineering as creative problem solving: a research agenda for idea finding. In *IEEE International Requirements Engineering Conference*, 2010.

[39] N. Maiden and J. Lockerbie. Creative Engine. http://becreative.city.ac.uk/index.php, 2018.

[40] N. Maiden, S. Manning, S. Robertson, and J. Greenwood. Integrating creativity workshops into structured requirements processes. In *ACM SIGCHI Conference on Designing Interactive Systems*, 2004.

[41] N. Maiden, C. Ncube, and S. Robertson. Can requirements be creative? Experiences with an enhanced air space management system. In *International Conference on Software Engineering*, 2007.

[42] N. Maiden and S. Robertson. Developing use cases and scenarios in the requirements process. In *International Conference on Software Engineering*, 2005.

[43] R. E. Mayer. Fifty years of creativity research. In R. J. Sternberg, editor, *Handbook of creativity*. Cambridge University Press, Cambridge, UK, 1999.

[44] E. McFadzean. The creativity continuum:towards a classification of creative problem solving techniques. *Journal of Creativity and Innovation Management*, 7(3), 1998.

[45] S. McKenna, D. Mazur, J. Agutter, and M. Meyer. Design activity framework for visualization design. *IEEE Transactions on Visualization and Computer Graphics*, 20(12), 2014.

[46] M. Michalko. *Thinkertoys: a handbook for creative-thinking techniques.* Ten Speed Press, Emeryville, CA, 2006.

[47] W. C. Miller. *The creative edge: fostering innovation where you work*. Basic Books, New York City, NY, USA, 1989.

[48] T. Munzner. A nested model for visualization design and validation. *IEEE Transactions on Visualization and Computer Graphics*, 15(6), 2009.

[49] Mycoted Inc. Creativity techniques: A to Z. https://www.mycoted.com/Category:Creativity_Techniques.

[50] R. S. Nickerson. Enhancing creativity. In R. J. Sternberg, editor, *Handbook of creativity*. Cambridge University Press, Cambridge, UK, 1999.

[51] C. Nobre, N. Gehlenborg, H. Coon, and A. Lex. Lineage: visualizing multivariate clinical data in genealogy graphs. *bioRxiv Preprint*, 2017.

[52] V. Nolan. Whatever happened to Synectics? *Creativity and Innovation Management*, 12(1), 2003.

[53] A. Osborn. *Applied immagination: principles and procedures of creative problem solving*. Charle Scribener's Sons, New York, USA, 1953.

[54] D. H. Rogers, C. Aragon, D. Keefe, E. Kerzner, N. McCurdy, M. Meyer, and F. Samsel. Discovery Jam. In *IEEE Vis (Workshops)*, 2016.

[55] D. H. Rogers, F. Samsel, C. Aragon, D. F. Keefe, N. McCurdy, E. Kerzner, and M. Meyer. Discovery Jam. In *IEEE Vis (Workshops)*, 2017.

[56] E. B. Sanders. Information, insipiration, and co-creation. In *Conference of the European Academy of Design*, 2005.

[57] E. B.-N. Sanders, E. Brandt, and T. Binder. A framework for organizing the tools and techniques of participatory design. In *Participatory Design*

Conference, 2010.

[58] K. R. Sawyer. *Group Creativity: music, theater, collaboration*. Lawrence Erlbaum Associates, Mahwah, New Jersey, 2003.

[59] K. R. Sawyer. *Explaining creativity - the science of human innovation*. Oxford University Press, 2006.

[60] M. Sedlmair, P. Isenberg, D. Baur, and A. Butz. Evaluating information visualization in large companies: challenges, experiences and recommendations. In *Proc. Workshop on BEyond Time and Errors: Novel EvaLuation Methods for Information Visualization*, 2010.

[61] M. Sedlmair, M. Meyer, and T. Munzner. Design study methodology: reflections from the trenches and the stacks. *IEEE Transactions on Visualization and Computer Graphics*, 18(12), 2012.

[62] B. Shneiderman, G. Fischer, M. Czerwinski, and B. Myers. Creativity support tools. In *NSF Workshop Report on Creativity Support Tools*, 2005.

[63] B. Shneiderman and C. Plaisant. Strategies for evaluating information visualization tools. In *Proc. Workshop on BEyond Time and Errors: Novel EvaLuation Methods for Information Visualization*, pages 1–7, 2006.

[64] R. B. Stanfield. *The workshop book: from individual creativity to group action*. New Society Publishers, Gabriola Island, BC, Canada, 2002.

[65] S. Thompson and N. Thompson. *The critically reflective practioner*. Palgrave Macmillan, New York, NY, USA, 2008.

[66] M. Tory and T. Moller. Human factors in visualization research. *IEEE Transactions on Visualization and Computer Graphics*, 10(1), 2004.

[67] R. S. Vosko. Where we learn shapes our learning. *New Directions for Adult and Continuing Education*, 50(Summer), 1991.

[68] R. Walker, A. Slingsby, J. Dykes, K. Xu, J. Wood, P. H. Nguyen, D. Stephens, B. L. W. Wong, and Y. Zheng. An extensible framework for provenance in human terrain visual analytics. *IEEE Transactions on Visualization and Computer Graphics*, 19(12), 2013.

[69] J. Wood, R. Beecham, and J. Dykes. Moving beyond sequential design : Reflections on a rich multi-channel approach to data visualization. *IEEE Transactions on Visualization and Computer Graphics*, 20(12), 2014.