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. Creativity workshops can help researchers to establish rapport with domain collaborators, to characterize domain problems, to understand analysis needs, and to explore visualization solutions. Although creativity workshops have been used successfully in a variety of recent projects, there are no established practices for how to use them effectively in visualization research. Through a methodology of critically reflective practice, we have analyzed our use of 17 creativity workshops in various applied visualization contexts. This paper contributes the results of our analysis, a framework that describes how and why to use visualization creativity workshops. The framework consists of a process model for analyzing the use of workshops, theoretical constructs for describing what happens in workshops, and a validated example workshop that can serve as a starting point for the use of workshops in future projects.

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

1 Introduction

The early, formative stages of visualization design work focus on identifying interesting visualization opportunities within a domain [61]. Typically, these stages rely on many hours of repeated interviews and observations with a set of stakeholders in order to discover and codify a set of common needs [29]. This lengthy process has a number of challenges, including building a strong rapport with the domain experts [63], as well as navigating organizational constraints [60]. A number of design studies, however, report on the use of *creativity workshops* — a structured participatory method that deliberately and explicitly fosters creative thinking [49] — as an alternative method for discovering visualization opportunities [11, 12, 13, 27, 47, 69]. These workshops typically bring together a small group of visualization designers and domain experts for a day of structured activities to explore opportunities for visualization by establishing open communication, building trust, and fostering *group creativity* [58]. The workshops can greatly reduce the time and effort of discovering cross-cutting needs, 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"* [27].

The term *creativity workshop* was introduced to the visualization community by Goodwin et al. [12] who report on their experiences using a series of workshops to discover visualization opportunities, to create designs, and to evaluate prototypes. This inspired subsequent work that used creativity workshops as a method to explore opportunities and requirements for visualization [13, 27, 47, 69]. But this work reported workshops with varying levels of detail. Kerzner et al. [27], for example, report on their workshop in one sentence. Despite the documented success of creativity workshops in the visualization design process, there is little existing guidance for the visualization community about what exactly creativity workshops are, why they are useful, or how to effectively use them.

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We searched existing literature on creativity and workshops for guidance on visualization creativity workshops [7, 14, 16, 42, 49], but existing resources provide little guidance on topics that are critically important to visualization research. These topics include: the graphical nature of data visualization [51]; the critical role of data early in the design process [43]; the wicked nature of visualization design and complexities associated with validation and evaluation [29, 37, 44]; the use of specialized process models [39, 40, 61, 67]; the developing knowledge base as visualization researchers and collaborators communicate and learn [71, 53]; and the associated evolution of data, tasks, requirements and designs that occur throughout a project [37].

This paper bridges the gap between existing workshop literature and visualization research, providing guidance for *creativity requirements workshops* used in the early, formative stages of applied work to discover, identify, explore, evaluate, and validate new and useful visualization opportunities, constraints, and considerations [12, 24]. The emphasis of this paper is not whether creativity workshops can make visualization research more creative — that is nearly impossible to rigorously measure in applied contexts [46]. Instead, we frame creativity workshops as a valuable method to promote focused thinking, to encourage open communication, and to foster exploration of relevant data, analysis, and visualization.

To provide guidance about how to design, execute, and analyze creativity requirements workshops in applied visualization research, we synthesize existing creativity workshop theory with experiential knowledge. The guidance results from a research methodology of *critically reflective practice* [3], including a meta-analysis of our collective experience and research outputs from conducting 17 creativity workshops in 10 different applied visualization contexts [11, 13, 12, 26, 27, 30, 47, 54, 55, 69], as well as a review of creativity workshop literature from the domains of design [1, 8, 10, 28, 57], software engineering [20, 23, 24, 25, 32, 34, 36] and creative problem solving [7, 14, 16, 42, 49].

This paper's **primary contribution** is the *visualization creativity workshop framework* which consists of:

- a process model for analyzing the common actions before, during, and after workshops;
- a description of workshop structure, providing guidance on how to craft effective workshops;
- detailed description of two workshop methods tailored for visualization; and
- a validated example workshop that can serve as a starting point for designing future workshops.

We tentatively offer a further contribution: our work exemplifies critically reflective practice that enables us to draw upon multiple diverse studies to generate new knowledge about visualization in practice.

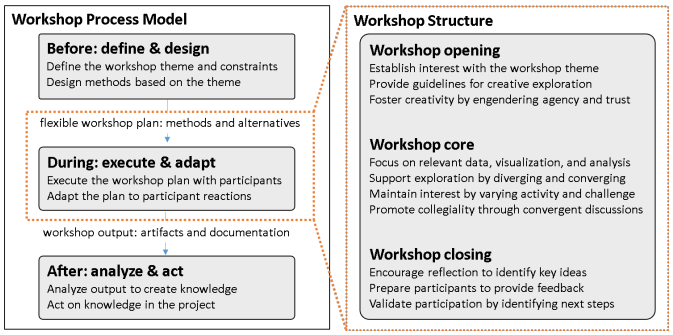

Fig. 1. The framework consists of two interconnected concepts: 1) the process model (left) describes how researchers use workshops — identifying three stages that map to before, during, and after the workshop; and 2) the workshop structure (right) describes how workshops themselves are organized — defining three phases of a workshop that correspond to the beginning, the middle, and the end. While the process model stages are clearly demarcated, the phases of workshops are more closely connected.

Next, we provide an overview of the framework which we use to organize the remainder of this paper.

2 Vis. Creativity Workshop Framework Overview

This introduce the visualization creativity workshop framework while also describing how this paper is organized. The framework results from analysis of relevant literature, which we describe in Sec. 3. We reviewed this literature as part of our reflective research methodology, described in Sec. 4, which also analyzed our diverse workshop experience, summarized in Sec. 5.

Our reflective analysis resulted in the framework, shown in Fig. 1, which consists of two interconnected concepts: the workshop process model and the workshop structure. The process model identifies three discrete stages that correspond to actions before, during, and after workshops. The workshop structure identifies three interconnected stages of methods within a workshop, that correspond to its beginning, middle, and end.

Because the stages of the workshop process are clearly demarcated, we present each stage of the process in a separate section. And, as the workshop structure describes what happens in a workshop, we present the framework as follows. Sec. 6 introduces the first stage of the process model, **define & design**, in which we define the purpose of a workshop and design appropriate methods. This stage results in a flexible **workshop plan** that describes the intended workshop methods and resolved practical concerns. To explore the contents of the workshop plan, Sec. 7 describes the workshop structure and examines specific workshop methods. Next, Sec. 8 examines the second stage of the process model, **execute & adapt**, in which we perform the workshop plan, adapting it to reactions from participants. This stage results in **workshop output**, a set of rich and descriptive artifacts, participant feedback, and notes documenting the experience. Then, Sec. 9 discusses the final stage of the process, **analyze & act**, in which we make sense of workshop output, creating insights that influence our actions. This stage results in knowledge integrated into the design process, for example, by creating prototypes inspired by ideas from the workshop. Finally, Sec. 10, discusses limitations of our research and identifies interesting areas for future work.

3 Background and Related Work

This section proposes a definition of visualization creativity workshops, describes their use in recent visualization projects, and summarizes their use in software engineering and creative problem solving.

Workshops are structured meetings focused a specific theme or goal [4]. We examine workshops as design **methods**, repeatable actions of researchers [6]. Some workshops consist of a single method, such as *visualization awareness workshops* and *domain visualization workshops*, where researchers engage collaborators using visualizations of either general or domain-specific data, respectively [64]. Commonly, workshops connect multiple methods to explore a theme in a variety of ways [4]. This paper is about the use of **visualization creativity workshops**, a structured series of participatory methods that deliberately and explicitly encourage creative thinking in applied visualization research. More specifically, we focus on *creativity requirements workshops* for understanding the analysis needs of diverse analysts.

A variety of recent projects document the use of visualization creativity workshops. Dykes et al. [11] used a series of three workshop-like *imagination exercises* that explored opportunities for enhancing map legends with visualization. Subsequently, Goodwin et al. [12] introducing the term *creativity workshop* to visualization when describing their experience using *creativity requirements workshops* to explore visualization opportunities, *creativity design concepts workshops* to create and iteratively refine prototypes, and *creativity evaluation workshops* to evaluate and validate prototypes. This inspired the use of creativity workshops in further projects as Walker et al. [69] applied a series of three workshops in a collaboration with defense analysts to understand needs, create designs, and evaluate prototypes. Consequentially, Kerzner et al. [27] and Goodwin et al. [13] applied full-day requirements workshops to understand the needs of neuroscientists and constraint programmers, respectively. And, Nobre et al. [47] used a half-day workshop to elicit requirements from analysts working with psychiatric data. Despite these reported successes of creativity workshops, no formal guidance exists for their use in applied visualization.

Visualization creativity workshops were based on creativity workshops for software requirements engineering [12]. In this domain, creative requirements workshops deliberately and explicitly encourage creative thinking to elicit requirements from stakeholders in large scale software projects [23, 34, 35, 36]. In these workshops, researchers guide 18 - 24 participants through 0.5 - 2 days of structured methods, generating hundreds of ideas for software systems [25] which can be used in requirements engineering processes [24] and agile development practices [19]. Software requirements workshops were themselves based on workshops for creative problem solving.

Creative problem solving is a broad field in which practitioners deliberately and explicitly foster creativity to articulate and solve problems, often in a business setting [48]. While there are many competing frameworks for workshops in this domain (e.g., Creative Problem Solving [5], Lateral Thinking [7], and Synectics [14]), their common principles 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 problem solving, and eliciting synergistic group creativity [46].

These principles relate to visualization research as we often establish rapport with domain collaborators [63], explore a broad space of possible designs before selecting the more promising ones [61], and recognize that visualizations are closely linked to the problem formulation [43]. Furthermore, visualization researchers can leverage existing practical guidance on workshops, including how to invite participants, present ideas, and facilitate discussions [4, 15, 16].

But, existing workshop guidance does not recognize the critical role of data early in the design process [31], the sharp focus on visual solutions to the problems in hand [52], and the close relationships between validation and evaluation in visualization research [29, 37, 44]. Thus, this paper is about analyzing, adapting, and adopting key ideas from creative problem solving, and software engineering to provide guidance on how and why to use visualization creativity workshops. Specifically, it contributes the first comprehensive analysis of visualization creativity workshops, based on reflection of our experience and involvement in *every* visualization creativity workshop described in this section.

ID	Year	Domain	Purpose	Result	Ref.	Prim.	Supp.
P1	2009	Cartography	*"Reimagining the legend as an exploratory visualization interface"*	InfoVis paper	[11]	JD	*
P2	2012	Smart Homes	Deliver insights into the role of smart homes and new business potential	InfoVis paper	[12]	SG	JD,SJ,*
P3	2012	Human terrain	*"develop [visualization] techniques that are meaningful in HTA"*	InfoVis paper	[69]	JD	*
P4	2015	Neuroscience	Explore problem-driven multivariate graph visualization	EuroVis paper	[27]	EK	MM, *
P5	2015	Constraint prog.	Design performance profiling methods for constraint programmers	VAST paper	[13]	SG	*
P6	2017	Psychiatry	Support visual analysis of determining or associated factors of suicide	TVCG paper	[47]	*	EK,*
P7	2017	Genealogy	Discover opportunities to support visual genealogy analysis	None	[26]	*	EK,MM,*
P8	2017	Biology	Support phylogenetic analysis with visualization software	Grant app.	[30]	*	EK,MM,*

Table 1. We analyzed the use of creativity workshops in 8 projects [P1–P8] which are diverse in terms of their domain, purpose, and results. We classify our involvement in these projects as the *primary researcher* or as a supporting researcher. The * represents individuals who were involved in each project but not co-authors of this paper.

ID	Theme	u	i	m	d	Focus	Facil.	Partic.	Hrs
P1.R	Explore possibilities for enhancing legends with visualizations	●	○			Req.	1v	3v / 5c	6
P1.D	Candidate solutions identified and considered in light of identified requirements	○	●	●		Des.	1v	3v / 5c	6
P1.E	Presentation and evaluation of deliverables	○	○	●		Eva.	1v	3v / 3c	4
P2.R	Identify future opportunities for utilising smart home data/technologies	●	○			Req.	2v / 1p	0v / 5c	6
P2.D1	Develop concepts from req. workshop in an agile approach	○	●	○		Des.	2v	6v / 0c	4
P2.D2	Elicit feedback from prototypes and prioritize design improvements	●	○	●		Des.	2v	0v / 7c	3
P2.E	Evaluate final prototypes	○	●	●		Eva.	2v	0v / 5c	3
P3.R	Identify novel visual approaches most suitable for HTA	●	○			Req.	1v / 1p	7v / 6c	9
P3.D	To further establish requirements ... to acquire feedback on initial designs	●	○	●		Des.	1v	6v / 3c	7
P3.E	Structured evaluation against scenarios	○	●	●		Eva.	1v	6v / 3c	4
P4.R	Explore shared user needs for visualization in retinal connectomics	●	○			Req	4v	0v / 9c	7
P5.R	Identify analysis and visualization opportunities for improved profiling of cons. prog.	●	○			Req.	2v / 1c	0v / 10c	7
P6.R	Understand the main tasks of psychiatric researchers	●	○			Req.	2v	1v / 6c	3
P7.R	Explore opportunities for a design study with genealogists	●	○			Req.	1v	3v / 7c	3
P8.R	Explore opportunities for funded collaboration between vis. and bio.	●	○			Req	1v / 1c	2v / 12c	7x2

Table 2. Our workshop experience, summarized by theme and categorized by activities in the design activity framework [39]: (u)nderstand user needs, (i)deate solutions, (m)ake and evaluate prototypes, as well as (d)eploy prototypes. As one workshop can influence many activities, we differentiate between explicitly focused activities (●) from more serendipitous or emergent activities (○). This categorization reveals three distinct, but related, workshop focuses as: requirements (understand, ideate), design (ideate, make), and evaluation (make, ideate). We describe the workshop facilitators and participants by their affiliation as (v)isualization researchers, (c)ollaborators, or (p)rofessional workshop facilitators.

Learning from Experience with Critically Reflective Practice

In applied visualization, reflection transforms engineering into research [61]. We use a methodology of critically reflective practice [3] to analyze our collective experience. Due to the nature of reflective analysis, we recognize that the framework is not exhaustive, predictive, nor objective. Nevertheless, *the framework is consistent with our experience, grounded in existing theory, and likely useful for future visualization research.*

4 Research Methods

This 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* [3], summarized as *"synthesizing experience, reflection, self-awareness and critical thinking to modify or change approaches to practice"* [66].

To learn from our experience, we examined rich and descriptive workshop data, including documentation, artifacts, participant feedback, and research outputs. We analyzed this data by applying qualitative analysis methods that embrace the metaphorical lenses of critically reflective practice [3], including:

- *the lens of our collective experience* — to make sense of our collective experience, we used interviews, discussions, as well as observation listing and observations-to-insights [28]. 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 literature of creativity and workshops[1, 5, 7, 14, 16, 42, 46, 49, 58, 59, 62] as well as visualization design theory [39, 43, 60, 67].
- *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. We analyzed their feedback and modified the framework to ensure that it is both actionable and consistent with existing practices.

While there are limitations to learning through reflective practice (see callout: Learning from Critically Reflective Practice), we support our contributions by providing a detailed description of significant reflective events and analysis methods in the Supplemental Material, along with an audit trail of documents that were produced throughout our two year reflective analysis and collaboration. Furthermore, throughout the text, we provide evidence of claims by explicitly referring to experience in projects and workshops, which we describe next.

5 Project and Workshop Experience

We analyzed 8 visualization projects that used 15 creativity workshops, summarized in Tab. 1 and Tab. 2 respectively, as well as 2 participatory and creative workshops with a variety of domain specialists at the World's leading visualization conference — IEEE Vis [54, 55]. As we analyzed more data than appeared in the resulting publications, including workshop artifacts and experiential knowledge, we refer to projects and workshops by unique identifiers throughout this paper, e.g., [P1] and [P1.R]. This section describes the projects in which we have used workshops as well as details about workshops, such as their intended result, duration, and number of participants.

5.1 Projects

The projects in which we have used workshops were conducted over the past 10 years. They span 8 distinct domains, including geographic information systems [P1], smart homes [P2], the life sciences [P4, P6 –

P8], and constraint programming [P5]. Their 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]. A majority of the projects resulted in publications in the visualization research literature [P1 – P6], one project resulted in a funding proposal [P8], and one project we consider to be a failure as it did not result in active collaboration [P7]. Furthermore, the projects were completed on three continents, conducted by researchers at City, University of London [P1 – P3], the University of Utah [P4, P6 – P8], and Monash University [P5]. The diversity of our projects, in terms of their location, domain collaborators, and outcomes provides evidence that creativity workshops are a valuable method for visualization researchers. It supports our claims of validity and contributes to the transferability of the framework.

We classify our involvement in each project as either a primary or supporting researcher. The **primary researcher** is responsible for deciding to use a workshop, executing the workshop, and integrating the workshop results into a collaboration through analysis and action. Alternatively, the **supporting researchers** may assist in the workshop process and provide guidance to the primary researcher. We have analyzed experiences as primary researchers [P1 – P5] and as supporting researchers [P6 – P7], contributing diverse perspectives to the framework.

5.2 Workshops

We describe workshops in terms of measurable characteristics, such as their duration. A majority of our workshops were about one working day in length [P1.R – P5.R], with other workshops ranging from a few hours [P6.R, P7.R] to a few days [P8.R]. We can also describe workshops in terms of the stakeholders involved as **facilitators**, who guide and document the workshop execution, as well as the number **participants**, who actually carry out the workshop methods. Our workshops typically included 1 – 4 facilitators guiding 5 – 17 participants through structured creativity methods. The facilitators were visualization researchers [P1.R, P4.R, P6.R, P7.R] assisted by professional facilitators [P2.R, P3.R], or domain collaborators [P5.R, P8.R]. Participants include analysts, managers, and support staff. The ratio of researchers to collaborators depends on the workshop's intended outcomes.

We characterize the workshops in our experience by their intended outcomes, abstracting and simplifying their role in the design process. Specifically, we retrospectively categorize workshops on how they fulfill *design activities* from the design activity framework [39], as shown in Tab. 2. Reinforcing the terminology of Goodwin et al. [12], we recognize three broad workshop focuses: **requirements workshops** generate an early understanding of user needs and explore how visualization could be used in a domain, often before significant efforts to create or develop prototypes [P1.R – P8.R]; **design workshops** either generate design ideas to guide development [P2.D1], or engage collaborators to evaluate designs and prototypes [P1.D, P2.D2, P3.D]; and **evaluation workshops** present and evaluate final prototypes, often to conclude a project [P1.E – P3.E].

Granted: characterizing workshops by their role in the design process is imperfect because design is a messy, iterative process and our actions often influence it in unpredictable ways. Furthermore, the boundaries between workshop focuses are nebulous, and, to some extent, all of our workshops could be considered requirements workshops because applied visualization research is about understanding and exploring new uses of visualization. Nevertheless, the workshop focus provides terminology to identify similarities between workshops that have the same intended result. Requirements workshops, for example, encourage wide ranging discussion of possibilities for visualization within a domain. Design and evaluation workshops are more narrowly focused around prototypes and the application of techniques to address and identify usage scenarios. The workshop focuses are also related to the time remaining for collaboration as requirements workshops can explore a variety of ideas early in the project, design workshops gather feedback to guide iterative development, and evaluation workshops have a more summative role in concluding projects, delivering outputs and presenting and evaluating prototypes of varying fidelity.

We developed the framework in this paper to understand how and why to use creativity requirements workshops in the early formative stages of applied research projects. We scope this paper on requirements workshops because it is the focus which we consider to be the most valuable as creativity requirements workshops offer an alternative to the traditional time consuming process of discussions, interviews, and contextual inquiry [61]. Furthermore, the subsequent design process is likely to be creative if linked to a preceding creative requirements workshop [12].

6 Before the Workshop: Define & Design

We start the workshop process by defining the scope of the workshop — identifying its theme, participants, and other factors — which we use to design the workshop — selecting and tailoring appropriate creativity methods. Here, we describe the actions of define and design sequentially, but in reality they are intertwined as designing a workshop causes us to revisit ideas about its scope. We preface the discussion of define and design with an answer to the following question: *should we run a workshop in our project?*

To answer this question, workshops can help to establish rapport with collaborators and to rapidly characterize domain challenges as well as specific analysis needs. More specifically, we have used workshops for reasons, including: to deliberately and explicitly stimulate creativity in a project [P2]; 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]. As this list is not exhaustive, there are likely other reasons to run workshops. We believe that workshops are a valuable method for practically all visualization research, regardless of the domain collaborators.

But, we recognize that there are scenarios where workshops will not be appropriate. As using workshops requires 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 conducted to scope some of the domain problems. In our failed workshop [P7.R], we did not know enough about the domain to effectively craft workshop methods. And, 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. Assuming that collaborators are engaged and present interesting opportunities for visualization, we decide to use a workshop and subsequently examine how to define the workshop purpose.

6.1 Define

Existing guidance on workshops emphasizes that it is critically important to articulate **workshop theme**, a statement of the workshop topics, goals, and intended outcome [4, 16]. This literature stresses that the theme should be narrowly focused on a specific topic, but open-ended enough to allow for exploring, discovering, and questioning workshop ideas [15]. In our experience, workshops can explore visualization opportunities for specific problems within a domain, as with the theme *"enhancing legends with visualizations"* [P1.R]. Workshops can also explore broad challenges of a domain — *"identify analysis and visualization opportunities for improved profiling of constraint programmers"* [P5.R]. More specifically, we tentatively offer guidelines about what makes an effective theme for visualization creativity workshops (see callout: Defining a *Visualization* Workshop Theme).

The theme helps us define *who will participate in the workshop?* We have recruited domain collaborators as participants, including frontline analysts [P6.R], a mix of analysts and support staff [P4.R], as well as a variety of practitioners, teachers, and students [P5.R]. We have used surveys to identify and recruit potential participants based on their responses to relevant questions and interest in participating in

Defining a *Visualization* Workshop Theme

The workshop theme summarizes the central topic of the workshop. Visualization creativity requirements workshops differ from workshops in other domains as their themes should aspire to:

- *Focus on interesting visualization opportunities* that identify a real need of analysts that exhibit the appropriate data location and task clarity [61].
- *Identify relevant analysts and domain data,* necessary to invite participants and tailor workshop methods to explicitly incorporate questions about data, analysis, and visualization.
- *Target results that benefit all project stakeholders,* including researchers, to better understand domain challenges, and collaborators, to think creatively about how they make sense of data.

a workshop. Surveys also provide relevant domain knowledge which is useful to design the workshop. Recruiting diverse and creative participants may contribute to successful workshops as a variety of perspectives enables exploration of broad challenges and ideas.

Additionally, a number of other workshop details should be defined early in the process. We have found the following questions useful to define a scope for the workshop. We offer answers to the questions as a vision for an effective workshop — but we recognize that our answers are not exhaustive, and that the characteristics of an effective workshop depend on the context where it will be used.

- *Who will help to facilitate the workshop?* An effective workshop is facilitated by visualization researchers, possibly with the help of domain collaborators, if domain vocabulary is complex and time is limited.
- *How long will the workshop be?* An effective creativity workshop lasts about one working day — while we have experience with shorter and longer workshops, these feel rushed or require too much time commitment from collaborators.
- *Where will the workshop be run?* It is run at a convenient location that allows collaborators to step away from their normal workflow — although creativity literature expounds the importance of neutral, well-lit venues, away from normal places of work [5, 22], and while such venues can be successful [P2.R, P3.R], we have also had success hosting workshops in on-site conference rooms [P4.R – P6.R].
- *What are additional workshop constraints?* It fits within other constraints which can include: the ability for collaborators to share data with researchers [P3, P6], whether project stakeholders have to travel significant distances for meetings [P1, P8], and the funding available for workshop materials.

The answers to these questions form the workshop's scope. We design the workshop within the constraints of the scope.

6.2 Design

We use the aforementioned decisions to create workshops that are relevant to the theme, appropriate for the participants, and possible within the project constraints. Creating workshops is a *design* problem as there is no single correct workshop, the ideal workshop depends on its intended outcomes, and the space of possible workshops is practically infinite. Thus, we create workshops through a design process of expressing, testing, evaluating, and improving ideas. We approach this design process from two perspectives. First, here, we analyze the actions of researchers who are designing workshops by selecting, tailoring, and testing methods that will promote creative thinking. Second, in the next section, we examine details about how methods can be assembled into a coherent workshop.

We select methods that promote group creativity, the synergistic and emergent creativity that results from cross-pollination of ideas made possible through open communication and focused work [58]. But group creativity relies on intangible and difficult to measure attributes such as how motivated or willing to communicate are the group members [46]. We have analyzed our experience to propose a concise set of factors that seem relevant to creativity in the context of applied visualization. The factors are consistent with existing creativity literature and can be used to provide actionable guidance about how to effective design and execute a creativity workshop. The factors are summarized in the box: *CACTI Factors for Creativity Workshops.*

Fostering Creativity with CACTI Factors

Reflecting on our experience, and reviewing relevant literature [46, 49, 58, 59, 62], reveals a number of key factors that influence the engagement and creativity of workshop participants: fostering, maintaining, and potentially varying the levels of collegiality, agency, challenge, trust and interest associated with each, as well as the focus on visualization and data in the context of the specialist domain. To help us remember these factors, we term them **CACTI factors**:

- (**C**)ollegiality – the degree to which communication and collaboration are encouraged and occur;
- (**A**)gency – the sense of participant ownership in workshop outcomes and research project;
- (**C**)hallenge – the barrier of entry to, and likelihood of success in workshop methods;
- (**T**)rust – the confidence that participants have in the methods, the design process, and the researcher's visualization expertise;
- (**I**)nterest – the amount of attention, energy and engagement to workshop methods;
- **+ −** other *relevance* factors that can effect: the levels of engagement with *data*, *visualization* and the *domain* in which collaborators are working.

The CACTI factors are neither independent, consistent, nor measurable. The extent to which they are fostered depends upon the context in which they are used, including various characteristics of the workshop group - often unknown in advance, though perhaps detectable by facilitators. And yet, maintaining appropriate levels of the factors likely helps workshops to inspire and engage participants while creating useful output and establishing lasting rapport among researchers and their collaborators.

With these factors in mind, we select workshop methods that fit within its constraints. For example, we outline a plan for the workshop such as start and end times, lunch, and coffee breaks. We then fill in time with appropriate methods which can be selected from a plethora of resources on creativity and workshops. Resources which we have found particularly useful include books [16, 18, 15, 28, 41], websites [33, 45], and research papers [38, 56]. While the methods in these resources target a range of domains outside of visualization, we typically adapt the methods for visualization to promote engagement with meaningful *data*, through *visualization* and tailor workshops to the specialist *domain*. In turn, this can achieve *trust* and *agency* and develop and maintain *interest*. We describe two methods which we have adapted for our workshops in Sec. 7.2.

In selecting methods it is critically important to test methods and the workshop plan through pilots. We have used pilots to test how understandable are methods [P2.R, P4.R]; to evaluate whether method prompts create interesting results [P6.R, P8.R]; and to find errors in method prompts and materials [P2.R, P4.R, P6.R, P8.R]. Pilots can be run with proxy workshop participants, such as visualizations researchers [P2.R] or domain collaborators [P8.R] — providing an opportunity to improve our understanding of the domain challenges. This improved understanding can cause us to revisit the workshop theme and participants, potentially influencing the workshop design. The result of design is a flexible workshop plan, which we describe next.

7 What Happens in a Workshop?

In this section, we step out of the process model to describe what happens in creativity workshops. The ideas in this section apply to both the workshop plan — as we design effective creativity methods — as well as the workshop execution — as we adapt the workshop to participant reactions. Specifically, here, we introduce a *workshop structure*, a pattern of how creativity methods can be assembled into coherent workshop. The workshop structure is illustrated by a validated example workshop contained in our Supplemental Material. To conclude this section, we examine two creativity methods, which appear in our example workshop, that are particularly effective for visualization creativity workshops.

7.1 Workshop Structure

The **workshop structure**, shown in Fig 1, provides an outline for organizing and combining creativity methods into a coherent workshop. It is based on our experience, as well as previous work that describes differences between the beginning, middle, and end of a workshop [4, 5, 16, 15, 41]. First, workshops begin with a **workshop opening** that can communicate why the workshop is being run and establish an atmosphere conducive to productivity and creativity. Next, the **workshop core** can promote group creativity and exploration of emergent ideas. Then, the **workshop closing** can conclude the workshop, providing validation, as well as a sense of achievement and agreement over next steps.

Similar to the *CACTI factors*, the workshop stages are open to interpretation and depend on who uses them, how, and in what contexts. For example, the workshop opening could be considered as the first two minutes, two hours, or two methods — all are valid. In other words, we introduce the workshop stages to organize workshop methods, but the boundaries between stages are ill-defined and effective workshops transition smoothly between stages, avoiding context switches that may distract or hinder participant *interest* in the workshop. Next, we propose guidelines for each of the three stages.

7.1.1 Workshop Opening

The workshop opening can communicate the goals and guidelines for participants, but can be more than that — it can foster *agency* by dispelling any assumptions that participation will be passive by encouraging self-expression, and idea generation. It can encourage *collegiality* and *trust* by promoting open communication and establishing a safe co-owned environment. The methods used in the opening should make clear that the workshop will be interesting, fun, and useful. Two characteristics are particularly important for the workshop, establishing a shared context and promoting activity.

First, we have opened workshops with a short introduction, framing the day as *"guided activities that are meant to help us understand: what would you like to do with visualization?"*[P4.R]. Alternatively, we used graphics that summarize the goals of our project to open the workshop, potentially priming participants to engage with *visualization* [P2.R]. Reiterating the workshop theme — often, the exploration of domain problems, visualization opportunities, and data analysis needs — can entice *interest* and establish a shared context for participants and facilitators.

The opening can also establish principles to deliberately and explicitly encourage creativity and promote effective workshop participation and facilitation [5, 49]. Example principles introduced at the beginning of one workshop include [P2.R]: all ideas are valid, express and record them; let everyone have their say; be supportive of others; instead of criticizing, create additional ideas; think 'possibility' – not implementation; speak in headlines and follow-up with detail; and switch off all electronic devices.

Yet, introduction presentations should be kept short to maintain *interest*. Passive methods, such as lectures and presentations, can discourage participation at the outset. For example, one workshop started with a presentation on the current state of analysis tools [P8.R], encouraging participants to passively listen rather than actively explore. Although we may need to vary levels of participation throughout a workshop, the outset should be active and energized.

Second, introduction methods can promote active and energized participants. One effective method, the *analogy introduction*, asks facilitators and participants to introduce themselves through analogy, e.g., *"if you were to describe yourself as an animal, what would you be?"* [P2.R]. Members of one academic lab with which we worked [P4.R], found this method particularly effective as it helped to establish *agency*, *collegiality*, and *trust* because it encouraged self-expression as everyone — from undergraduates to senior researchers — demonstrated vulnerability. Our experience suggests that this levelling can help develop *collegiality* between participants at different levels within an organization and also participants with expertise in different domains. Using analogy also primes participants to think creatively about how concepts from visualization could apply to their domain.

7.1.2 Workshop Core

The workshop core harnesses the active and engaged mindset of participants, encouraging them to explore, create, and record ideas, potentially generating hundreds of post-it notes, sketches, and other artifacts. While the core can appear chaotic, the methods can be characterized by certain attributes which follow a pattern to foster creativity.

First, methods can focus on generating ideas — exploring a broad space of possibilities — followed by evaluating ideas — winnowing the ideaspace to the more interesting or promising ideas. Methods used in the workshop core should provide opportunity for both kinds of activity, cycling through **divergent methods** that expand the workshop ideaspace, and **convergent methods** that winnow the ideaspace to the more promising or interesting ideas [49]. Classifying methods as divergent or convergent risks oversimplification as individual methods often include both divergent and convergent aspects, but designers can judge whether the overall goal of an activity is to expand or contract the ideaspace. Consider our use of *brainstorming* [49] during one workshop [P1.R] in which participants recorded *"problems and successes associated with the current clients on sticky notes"* (divergent) and then shared the ideas that participants considered to be most interesting (convergent). As this method primarily generates artifacts representing the problems and successes, we consider it to be divergent, despite the convergent ranking of ideas. Within the brainstorming method, encouraging all participants to communicate promotes *collegiality* and asking individuals to converge through their prioritization aims to engender *agency*. In contrast, a primarily convergent method may involve ranking or grouping post-it notes from previous methods, perhaps through mixed groups to develop *collegiality*. Characterizing methods as divergent or convergent, and subsequently structuring the workshop to promote cycles of divergent and convergent thinking provides a foundation for the workshop core. Specifically, using divergent methods early in the workshop encourages ideation, promoting *agency* and establishing *interest*. Convergent methods can refocus the ideaspace on interesting topics that are most relevant to the role of *visualization* in the *domain*.

Second, methods can be characterized as **active methods** — encouraging engagement and exploration — or **passive methods** — providing time for incubation, the conscious and unconscious combination of ideas [59]. Passive methods can include unstructured breaks between methods, informal discussions over meals, or methods where participants listen to presentations. Asking participants to reflect upon presentation contents and record reactions can promote *interest* in a primarily passive method that is intended to vary the levels of energy and enable individual reflection. We have typically used passive methods in the second half of full day workshops, to provide incubation after lunch [P2.R, P4.R, P5.R, P8.R].

Third, methods can be described by how they encourage participants to **externalize ideas**, creating physical artifacts representing ideas. Externalization can encourage creative thinking, as physically expressing an idea forces the creator to elaborate and improve it [59]. It is also important for promoting *collegiality* as physical representations support the communication of ideas. Post-it notes are a particularly useful form of externalization that we have used in all of our requirements workshops as they enable analysis of grouping or rank-

ing recorded ideas [9]. Using post-it note color to encode information, such as the method or specific prompt that generated an idea, can provide insight structure to the method, help with recording and be a useful aid during analysis as it can establish how ideas evolved and were valued through the workshop. Additional materials effective for externalizing ideas include structured prompts or poster boards for *brainstorming*. The use of whiteboards is tempting, but ideas can be lost if the boards are erased. As we use workshops to create artifacts that express the needs and concerns of collaborators, methods can be selected by how they encourage participants to externalize and analyze ideas.

Fourth, the relationships among methods can be considered as workshops can balance divergence and convergence, provide time for activity and rest, as well as use a variety of mediums for externalization. Striving for variety among these factors can help to vary the *challenge* of methods — for example, as methods that require drawing ideas may be considered more *challenging* than discussions. It can also help to maintain *interest*, for example, by providing breaks from continuously generating ideas which is potentially tiring. And, it is useful for facilitators, for example, to provide breaks from actively guiding participants that may be used for reflection and workshop redesign. Thus, the design of workshops should select methods that provide balance and variety to participants as well as facilitators.

Fifth, to maintain an atmosphere of *collegiality* and preserve participant *interest*, potentially jarring transitions should be avoided between methods. Convergent discussions can be used to conclude individual methods, such as through discussion of 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. Similarly, convergent methods can conclude the workshop core. This includes methods to group, rank, or summarize ideas from the day. In our two day workshop, we concluded the first day by clustering ideas to identify *springboards* [14], that we explored during the second day [P8.R]. We have used *storyboarding*, to encourage the synthesis of ideas into a single narrative [P2.R, P4.R P5.R]. We have also asked participants to explicitly rank ideas, providing cues for analyzing the workshop results [P2.D2, P3.R]. Overall, convergence is an important aspect to conclude individual methods as well as transition from the workshop core to the workshop closing.

7.1.3 Workshop Closing

The end of the workshop sets the tone for continued collaboration in the project. It is an opportunity to promote creativity and engagement through three key factors: by reflecting on the shared creative experience, by validating the time and energy that participants have contributed, and by identifying the next steps of action.

First, discussions during the closing can 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?"* [P2.R] or ,*"what will you do differently tomorrow given what you have learned today?"* [P5.R] 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.R]. Also, because reflective questions are used to start a discussion, they require participants to rank their thoughts and to talk about the more interesting ones. Recording these ideas can provide important clues for the analysis of workshop artifacts, such as in our neuroscience workshop's closing where discussions about *"multi-hop path queries"* resulted in focusing on connectivity analysis [P4.R].

Second, effective closings can prepare participants to provide feedback on their experiences. Analyzing feedback enables the workshop team to reflect on the execution and the efficacy of specific methods. 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.R]. Recently, we have used online surveys to gather feedback on the effectiveness of the workshop, specific methods, and the facilitation style. While the closing is an appropriate time to ask for feedback, responses to online surveys can be spread over days and may require additional reminders. We have asked participants for feedback during the workshop [P2.R], but do not yet understand how providing time for incubation or enabling anonymous responses influences the results.

Third, identifying the next steps of action can validate participant involvement, as the workshop facilitators can explain how the ideas will be used to move the collaboration forward — this includes any post-session feedback, but also the analysis and action planned, as we describe in Sec. 9.

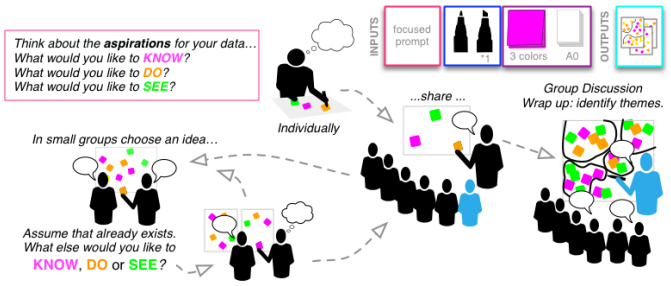

Fig. 2. In *Wishful Thinking*, we prompt participants with a domain-specific scenario and ask to record ideas about what they would like to know, to see, or to do.

7.2 Workshop Methods

The workshop structure provides high-level scaffolding within which specific creativity methods are selected for use in the workshop. Here, we describe two methods which we have adapted for visualization by focusing on the *relevance factors* of *data* and *visualization*.

7.2.1 Wishful Thinking

Early in the core of our workshops, the wishful thinking method proved useful as an active divergent method in which we ask participants about their goals for data analysis and visualization [P2.R, P4.R – P8.R]. Extending a method called aspirational thinking [38] with explicit language for visualization, we prompt participants with a domain scenario and ask for responses to the following questions: *"What would you like to know? What would you like to do? What would you like to see?"*. The questions responses, typically recorded on different color post-it notes, provide information useful at different points in the design process as 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 visualization focus is established early in the workshop.

As responses to these questions shape the ideas discussed in the workshop as well as subsequent decisions about creating and evaluating visualizations, we tailor the prompt to the specific domain and project goals. When exploring long term goals for emerging technology [P2.R], we asked participants about their *"aspirations for the SmartHome programme..."*, which generated forward-thinking ideas about energy consumption, such as to better understand *"the value of the data."* Working on collaborations to understand current analysis needs, we asked neuroscientists [P4.R], *"suppose you are analyzing a connectome..."* and constraint programmers [P5.R], *"your program does not execute as expected..."* Participant responses revealed shorter term goals, to *"to understand neuron connectivity"* and to *"explore the [solver] search space,"* respectively.

We outline a process for this method, shown in Fig. 2, that starts with an individual activity of generating ideas, providing a gentle step from opening into the workshop core. This, and then sharing ideas fosters inclusive (*collegiality*), promotes *agency*, and can prompt a wide

range of ideas. To *challenge* the participants, the activities get progressively more difficult as participants form small groups and start to iterate and build upon these ideas by assuming that the initial idea has already been implemented [P2.R,P5.R]. This *collegiate* incremental way of increasing *challenge* has been useful and effective in generating divergent ideas and prioritizing them in a number of projects. As an alternative we have also used hierarchical discussion, from small group to large group discussion, to explore interesting ideas [P4.R]. The effective process for this method is one that encourages participants to think broadly and deeply in generating and assessing useful ideas, which may require adapting it to the reactions of participants in light of the CACTI factors.

7.2.2 Visualization Analogies

Later in the workshop core, the *visualization analogies* method is a passive method that can promote incubation while also generating ideas about how visualization may apply to the domain. Similar to analogy-based creativity methods [14], we present a curated collection of visualizations and ask participants to individually record ideas about how the visualizations may apply to their domain and what aspects of the visualizations they like or dislike. Although this method is primarily passive, participants report that it is engaging and inspiring to see the broad possibilities of visualization and relate them to their problems. This activity is low on *collegiality* and *challenge*, but is intended to have positive effects on *trust*, *interest* and *relevance*.

Because the visualizations will influence the ideaspace, we reflected on our experience to identify a mix of objectives for our visualization examples, including: those 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); unrelated examples (to promote 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.R], *"what does it mean for energy to flow?"* [P2.R], and *"what does it mean for neurons to rhyme?"* [P4.R]. The diverse examples are important to prepare with care as they can not only result in increased *interest* but also in the participant's *trust* in researcher's domain expertise.

The process of this method involves a limited *challenge* as participants are encouraged to think (usually, initially) independently about how visualizations apply to their domain and make selections. Subsequent group discussions on these visualizations prompts additional *collegiality* and may increase *agency*. Providing paper handouts that contain a representative image of each visualization enables participants to annotate or otherwise externalize their ideas about certain visualizations, perhaps reducing any *challenging* barriers associated with engaging with the unfamiliar visualization domain [P4.R,P5.R,P8.R]. We have not had experiences in which domain experts have found it difficult to express opinions about visualization likes and dislikes, or to use analogy to engage in ideation about design possibilities and have known this activity to develop improved understanding of the domain.

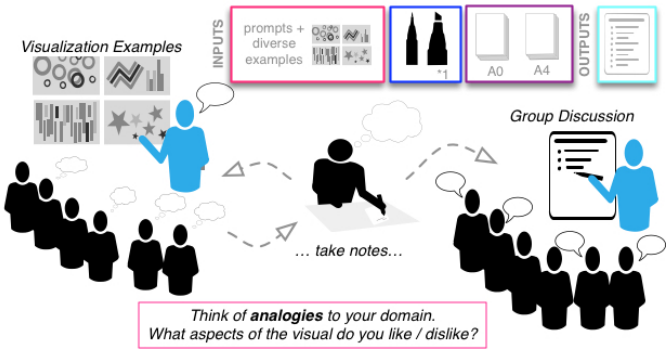

Fig. 3. In *Visualization Analogies*, we present visualization examples to participants while they record ideas about how the visualization may apply to their domain.

8 During The Workshop: Execute & Adapt

In this section we return to the workshop process model, analyzing how workshops are executed. Although the workshop plan describes what we intend to, executing the workshop is a performance where facilitators guide participants through methods and adapt the plan based on participants' reactions. Here, we discuss how preparation can support successful execution. Next, we describe the importance of limiting distractions, creating artifacts, guiding conversations, and adapting the workshop to the changing environment.

8.1 Execute

The foundation for effective execution can be laid before the workshop, through preparing facilitators, materials, and venue. Facilitators should review principles for effective execution from workshop literature (e.g., [4, 5, 16, 15, 65]), which include: being professional, demonstrating acceptance, being energized, providing encouragement, using humor, being punctual. Facilitators should also gather the correct materials for the workshop — we have mistakenly bought post-it notes that are too big, causing participants to write more than one idea on a sheet and making it challenging to use methods that involve sorting or ranking ideas. And, facilitators should prepare the venue as the furniture arrangement should promote a feeling of co-ownership and encourage participation — a semi-circle seating arrangement works well for this [68]. A mistake in one of our workshops was to have the speaker using a podium, which implied a hierarchy between facilitators and participants, hindering communication [54].

One benefit of workshops is that they provide a time for participants and facilitators to step away from their normal responsibilities and focus on the collaboration. Accordingly, participants, as well as facilitators, should be focused on the workshop without distractions, such as leaving for a meeting or checking e-mail. In our experience, a major source of distraction is when facilitators and participants communicate with people outside of the workshop and this should be discouraged. Clearly communicating that the workshop will require focused thinking should be communicated while recruiting participants and facilitators, and it should be reinforced in the workshop opening (e.g., *switch off all electronic devices*).

Another consideration to reinforce at the start of the workshop: conversations are ephemeral and anything not written down will likely be forgotten. Thus, execution should focus on creating artifacts that capture the workshop ideaspace. Audio recording of the workshop can be useful for shorter workshops [P6.R], but audio for longer workshops may not be useful as it requires tremendous time to transcribe and analyze [31]. It follows that we make an effort to document all activities in the workshop, by note taking or through methods that create artifacts. The workshop team must know the expectations for note taking and pilot workshops will help with this. A pilot for [P5.R] for example, may have reduced the note taking pressure on the primary researcher during the day.

As the execution progresses, the facilitators guide participant through activities, allowing for exploration but moving toward a common goal. Conversations that deviate from the day's focus should be redirected, but this requires careful judgment to determine whether a conversation is likely to be fruitful and sensitivity about the CACTI factors — e.g., how would redirecting this conversation influence *collegiality* or *agency*? When allowed to discuss freely, participants commented *"we had a tendency to get distracted [during discussions]"*[P4.R]. Whereas more active guidance resulted in feedback: *"we were guided and kept from going too far off track despite our tendencies to do so. This was very effective"* [P8.R]. Yet, redirection can be jolting and can contradict some of the agreed guidelines (e.g., *"all ideas are valid!"*). It may be beneficial to 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."

8.2 Adapt

As facilitators guide the workshop, they can interpret group dynamics to adapt to the changing situation. If participants do not find a method helpful, they may propose their own as when analysts proposed walking through visualization analysis scenarios in place of a planned method [P3.R]. Facilitators should be prepared for flexibility, perhaps by having alternative methods planned or by being ready to improvise. It requires judgment to deviate from the plan, and the design considerations should be considered on-the-fly as the workshop adapts to participant responses.

The CACTI factors, from Sec. 7, should be considered while adapting the workshop as facilitators respond to changing situations 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*) or a lack of agency (*some participants dominate some tasks*). Designing the workshop with alternative methods in mind — perhaps with varying degrees of *challenge* — can ensure that facilitators are prepared to adapt the workshop effectively.

9 After the Workshop: Analyze & Act

After the workshop we make sense of its output, creating actionable knowledge that can influence the continued creative collaboration. For clarity we describe how we make sense of the artifacts, followed by how we have used artifacts throughout the collaboration. But, in our experience analysis and action are intertwined.

9.1 Analyze

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

Typically, the primary researcher analyzes the output as they are using it to shape an ongoing design conversation with their collaborators. Clearly identifying the primary researcher before this stage is important as they decide how to analyze the workshop output and what to do with the results of that analysis. In our failed project [P7.R], we ran a workshop without clearly identifying the primary researcher, and workshop output went unused.

In our experience, we have analyzed workshop output by typing or photographing artifacts into documents or spreadsheets, allowing us to become familiar with all ideas in the artifacts. This also enables sharing the output to enlist diverse stakeholders — such as collaborators or other workshop team members — in making sense of the results and clarifying ambiguous requirements. This is particularly important in domains with complex vocabulary.

The specific analysis methods will depend on the form of the artifacts which is directly influenced by workshop methods. In most cases [P2.R, P4.R – P7.R], we used qualitative analysis methods – open coding, mindmapping, and other less formal processes – to group workshop artifacts into common themes or tasks. We often ranked these themes and tasks by various criteria, including, novelty, ease of development, potential impact on the domain, and relevance to the collaboration. In other cases [P1.R, P3.R], workshop methods generated specific requirements, tasks, or scenarios that could be editing for clarity and directly integrated into the design process. Quantitative analysis methods should be approached with caution as the frequency of an idea provides little information about its novelty, usefulness, or potential impact. The insights gleaned from analysis will influence many aspects of the remaining design process.

9.2 Act

We have used the results of analysis to scope traditional user-centered design methods, such as interviews and contextual inquiry. For example, a common theme of output from our neuroscience workshop was to *"analyze multi-hop relationships"* [P4.R]. Using this theme, we focused interviews on the challenges of analyzing connectivity, revealing low-level tasks that inspired subsequent prototypes.

The results of the workshop can be used to create prototypes of varying fidelity, from sketches to functioning software. For example, we have used the workshop output in parallel prototyping [P4.R,P5.R,], as well as to decide on features for in-development software tools [P6.R], as one of our collaborators who used the workshop told us *"I personally got a much better understanding of what they were trying to do and what information they needed to do it ... which ultimately guided our design decisions."* In other cases [P1.R — P3.R], we have used the workshop output as input to additional workshops focused on rapidly exploring the possibilities for visualization design.

These activities may adapt existing software to newly discovered analysis needs or explore entirely new visualization techniques as in our neuroscience project P4.R, where the outputs inspired plugins for existing tools that we iteratively developed into a novel visualization technique. In all of these cases, our actions can be considered divergent — expanding space of possible visualization designs currently being considered. The results can be used in convergent design methods — contracting the space of possible visualization designs. The workshop output can involve design considerations, such as reaching *"everything in three clicks"* [P2.R] and providing *"access [to] underlying database keys"* [P4.R] from visualizations. These criteria can be used to winnow the space of possibilities, for example, to evaluate, focus, and refine designs and prototypes.

We emphasize that analyzing the output and acting on the results of analysis occur iteratively and that workshop output should be revisited throughout the project. Workshop artifacts can provide valuable evidence about the contributions of applied work as they can document that visualization systems fulfill real analysis needs. They can also be used to document the evolution of ideas that occurs throughout design studies.

10 Discussion

In this section, we reflect on the framework that we have created. We describe its implications about role of documentation and reflection in visualization research. Next, we describe the extent to which workshops follow, or break, established visualization research practices. Then, we conclude with the multitude of areas for future research.

The visualization creativity workshop framework, its supporting evidence referenced throughout the text, and audit trail in the Supplemental Material, illustrate the use of reflection as a research methodology and show the critical role of documentation in visualization research. Although we maintained documentation of our collaboration in an adhoc fashion, this was critically important for our analysis and writing. In particular, shared documents evolved with our understanding of workshops and were continuously revised with our opinions, experience descriptions, and literature references. Moreover, we referred to documentation from workshops spanning more than 10 years — this analysis would have been impossible without well-preserved records. We hope that the audit trail inspires future thinking on how to document and preserve the decisions through visualization collaborations. This could be particularly useful to document the experiences of future visualization creativity workshops. While we present this approach as a means of establishing knowledge about visualization in practice through evidence generated in multiple diverse studies, we would also like to better understand and apply the methods that are most appropriate for future reflective analysis.

Our reflective analysis revealed discrepancies between what we do in visualization design methods and what we do in workshops: visualization research stresses the importance of designing with real data, but practically all of our requirements workshop methods asked participants about their perceptions of data rather than incorporating real data. On one hand, this could be due to the time required for working with real data exceeding the time available for a workshop — and high-level visualization design tools may change this. But, on the other hand, incorporating real data into workshops may distract from their

creative potential. In one of our workshops [55], providing workstations with domain data distracted participants as their creative thinking became mired in data parsing and wrangling. Accordingly, we would like to better understand the tradeoffs associated with asking participants about real or perceived data in future workshops.

In addition to incorporating real data, we are excited to explore method variations based on the rich literature of visualization design methods. This includes the use of tangible artifacts — building blocks, tiles, or other physical media — to construct visualizations [21]. We are interested in understanding how the *active reading of visualizations* [70] could be integrated into workshops as it potential provides deeper engagement with concepts at hand. We are also interested in using different types of creativity stimuli, including ambiguity [10], pseudo-profound bullshit [50], as well as many other creativity triggers [1].

We would also like to explore the potential use of workshops beyond domain analysts, potentially using workshops to elicit requirements from casual visualization consumers who may appreciate visualizations for their aesthetic or playful qualities [37]. We suspect that workshop methods could be tailored for interacting with casual users, such as by encouraging the elicitation of emotional responses to visualization [17].

Lastly, throughout this paper we focused on visualization creativity requirements workshops. We would like to explore how the framework could be extended for other types of workshops — including, for design and evaluation of prototypes. We see this framework as the first step toward understanding how and why to use creativity workshops in applied research.

11 Conclusion

This paper contributes a framework for thinking about how to use creativity workshops in applied visualization research. The framework is based on critical reflection of our experience and grounded in existing theory of creativity, workshops, and visualization. It provides guidance on the process of using workshops as well as describes what happens within workshops. We envision continued use of workshops in virtually every applied research project that requires eliciting visualization requirements from diverse stakeholders. We hope that this framework inspires others to use and report on creativity workshops in their projects.

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