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Thoughts and Reflections on Managing Learning Activities Using Creative Visualization

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ABSTRACT

Nine techniques for imaginative visualization exercises are included in this study. Running learning exercises where students complete tasks that directly support one or more of the concepts the teacher wants to cover in the lesson is a common way to teach visualization. We evaluate our own learning experiences as a team of educators and visualization researchers. Our experiences and actions include breaking the assignments up into smaller components, taking into account various educational resources, and promoting discussion. It is our aim that this document will inspire, motivate, and help other instructors with visualization exercises. Our observations offer a foundation for creating best practices in visualization education as well as a first starting point for techniques and strategies to create imaginative visualisation learning experiences.

Keywords: Data visualization, Information visualization, Scientific visualization, VisActivites, Learning activities, Pedagogy.

1 INTRODUCTION

In data visualization, creativity is the capacity to pose novel and pertinent queries and identify novel and suitable data representations. Visualization activities are practical assignments that aim to teach, reflect, discuss, or create data visualizations [36]. This is one method that students can interact with data visualization. The advantages of an active learning approach are numerous. It pushes people to think critically about the issue, improves memory, inspires risk-taking and the generation of fresh, innovative ideas, and fosters teamwork in a group context. In recent years, there has been a growing interest in and discussion of visualisation activities, as evidenced by a special issue [5] and multiple workshops [36, 37]. After giving it some thought, we authors began to consider what we could learn and whether we could create rules. The activities included in this article were developed by visualization designers and researchers and used for a variety of audiences and in a wide range of circumstances.

others may be tactile, others may entail sketching, and some may require finding and gathering various examples of visualization. Both participants and instructors usually follow a set of steps during an activity. Activities can range in length from a few minutes to many weeks, and they can use digital visualization tools (e.g., Tableau, D3.js), analog tools like pen and paper [80], or common physical items [40]. The aim is the same regardless of the activity's style or type: encourage people to think creatively and playfully about the issues. What can we learn, though? Are there overarching guidelines for best practices? Is it possible for us to develop some guides?This essay examines how humans plan, organize, and conceptualize activities. A set of nine considerations is presented (Fig. 1).

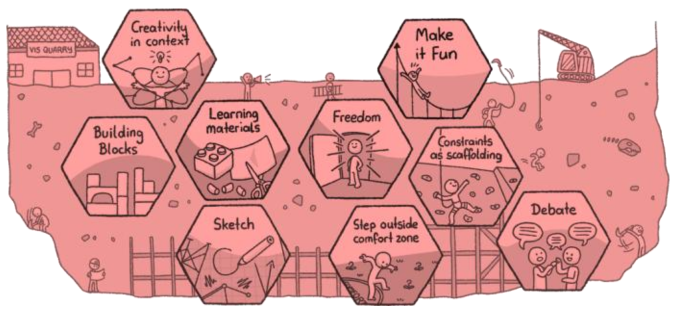

Figure 1: Nine reflections on creative visualization learning activities.

These are a representative sampling, a moment in time of thoughts. We hope that these will facilitate community conversation and serve as a springboard for people to think about best practices and lessons learned. Our long-term objective is to assist the community in creating guidelines and best practices that will stimulate innovative thinking. Our goal is to push teachers to think creatively and incorporate innovative activities into their lessons. Our goal is to encourage students to take a diverse approach to learning. Following an explanation of the methodology and background, we provide the nine tactics for creative visualization exercises (Sections 3–11) and then have a conversation.

2 BACKGROUND AND METHODS

The article was inspired by talks at workshops on VisAc-tivities [36,37], which covered education and activities in detail, and by discussions at the 2022 Schloss Dagstuhl seminar "Visualization Empowerment: How to teach and learn" [4]. We began sharing our experiences, difficulties, and methods after getting together to talk about creativity in visualization and become enthusiastic about everything creative in visualization. We came to the realization that some of our thoughts were novel, even though we all shared some similarities. We used many computer technologies in our instruction, and languages, as well as a range of materials, books, and exercises. Miro boards, Google Docs, shared photos, webpages, and other resources were used in the Dagstuhl lecture. We were gaining knowledge, skills, and experiences from one another. We started to consider whether we could modify a group exercise for our own instruction. Better yet, our thoughts and insights might be turned into a set of principles that others could follow.

All of the writers are academics and instructors in the field of data visualization. Our backgrounds are wide and varied. We provide courses to the general public as well as undergraduate and graduate students, with class sizes ranging from small (10) to large (150). We are all beginning to teach to people with broader skills, even though the majority of the students we teach have backgrounds primarily in engineering, data science, human-computer interaction, and computing. Some of the group taught at design schools, and others taught to students in the fields of biomedical engineering, design, economics, mathematics, statistics, medicine, and information systems. When we talked about our teaching strategies, resources, and methods of assessment (together, we covered the entire spectrum of coursework, graded exercises, and end-of-course exams), it became even more clear how diverse and varied the educators at the seminar were. After talking about and reviewing our histories, we gave students several tasks to complete and asked them to use various tools, such as Processing, JavaScript, R/ggplot, or Tableau, to apply their answers. Through this conversation, we came to understand that by selecting one of these resources, we, as the instructor, were helping the students acquire new abilities. For example, Tableau promotes users to think at a higher level of abstraction, while Processing encourages users to break the answer down into marks on the page.

The Five Design-sheet method for visualization design [63], data comics and storytelling workshops [6], design immersion techniques [33], tangible visualization with physical tokens [46], sketching exercises for visualizing two quantities [60], gamification [1, 43], techniques for eliciting self-reflection on personal data [78], critical thinking sheets [66], engaging people with physicalization [40, 61], stealth learning [20], and activities to improve data literacy [10, 34] were among the visualization activities we discussed together.

During the preparation and execution of activities, educators must deal with a variety of issues, discover the best answers for a wide range of characteristics, or swiftly analyze a developing situation in situ and respond to it as best they can. Planning an activity, for instance, raises concerns about the (learning) objectives, the time and materials needed, the level of assistance offered, the resources available to carry out the activity, and maybe the necessity of an assessment. In addition to the traditional limitations of time and location, contextual parameters also include the number of participants, their histories and abilities, etc. Eventually, either by themselves or with the assistance of other facilitators, an educator may need to oversee and moderate the activity while it is underway. They will need to provide clear instructions, guide participants, provide effective materials, and respond to any circumstances that could jeopardize the activity, participant experience, or learning objectives. It takes expertise and implicit knowledge of people, planning, or facilitation to overcome these obstacles. We address these unanswered questions in the context of creativity and offer methods to explain how teachers address these problems in their practices, including the objectives they pursue, the choices they make, and the lessons they discover.

We used a three-step process to compile the thoughts and considerations. First, following a preliminary conversation, we each put forward proposals. We began organizing the concepts using an affinity diagramming technique. combining concepts that were comparable. We gave them names, which served to both summarize the idea and make it easier for us to remember them later. We all made changes and collaborated on the concepts using a live Google document. We compiled a list of more than twenty-five suggestions from these. Second, we had a thorough conversation regarding the concepts, spoke about whether There were more, and some of them might be combined. We questioned the concepts, asking whether any lessons could be drawn and how they may be applied. In order to help transform abstract concepts into principles, we also desired a specific example for each. At this point, we combined some, added more, and removed some. In the end, we separated the work into nine major reflections and considerations, and each author selected the approaches they wished to take the lead on or work with. The number nine was selected at random. There was a delicate balance between too much and too little. We needed a representative sample that reflected the group's diversity in backgrounds and teaching experience, as well as a thorough list of topics to explore. The nine techniques are described in Fig. 1.

Figure 2: **Top:** Some participants of "You named it!" activity are com- paring data phys cards to assemble design patterns of physicalization (2018). **Middle:** Visualization made of wooden tiles with Collectif Bam kit during Viskit activity at Super Demain (2016). **Bottom:** Kids showing visualization made out of LEGO blocks during an activity. (CC BY 2.0 Sylvia Fredriksson).

Supporting, encouraging, and mentoring other educators in their visualization pursuits is our aim. The following nine thoughts, which are not presented in any particular order, are all first-person accounts from one or more of the authors. Each reflection starts with a personal narrative, discusses challenges and possible solutions, and ends with some closing remarks. Combining these ideas enables us to make educated guesses about open research and activity questions.

3 INTRODUCE COMPOSITION THROUGH CONCRETE AND CONCEPTUAL BUILDING BLOCKS

Simple components that can be put together to create something larger are known as building blocks. Youngsters learn to count by using their fingers, where one is represented by each finger. The youngster can count in tens by assigning ten to a finger. For children, physical building blocks have become well-known brands (LEGO, Fidget, Kapla, Meccano, etc.). They have been used to teach math in kindergarten [50], design and computer programming in K–12 [53], and other subjects. Building blocks can be conceptualized and abstracted. For example, conceptual building blocks for visualization are Bertin's visual variables [9]. Additionally, card games might use conceptual building blocks (see Fig. 2) to encourage innovation by making creation simpler. For those who are not professionals in visualization, building blocks are especially helpful. In the lab [42] and at home [78], anyone can easily develop, update, explain, and reflect through their own visualization using basic tangible building components.
As a result, numerous pedagogical activities and frameworks have been developed by researchers (see examples in Fig. 2). Building blocks, whether tangible or abstract, have been utilized to encourage students to create or even dissect information visualization schemes [38, 45, 58, 79, 83]. The process of building a visualization by assembling pieces that have already been given a data unit is known as construction [39]. On the other hand, "the process of identifying and deconstructing a problem---" at home [78] and [42].

Figure 3: Paper chains of human figures, representing data about asylum seekers.

Students can improve their ability to comprehend, evaluate, and create meaningful graphics by taking an atic graph and then reassembling it in a more suitable format [58]. As educators, we might begin to think about what can be built, what can beutilized as a building brick, and so forth. Measurements of clay or liquid paint are examples of raw materials that can represent data values [74]. For instance, people's heights can be represented by the length of drinking straws. Any idea or thing that can be broken down into separate components that can be put together.

Building blocks have been shown to simplify and expedite the visualization creation process while standardizing the outcomes by imposing a structure. They also enable the creation of engaging creative activities. The goal of building blocks is to break down complexity into numerous smaller manipulable and modular parts. You can use everything, both physically and theoretically.

Data, design, mapping, interactivity, and other facets of visualization may all be taught with them.

MAKE IT FUN

Having a great time, and enjoying the experience. We are more creative when we are having fun. We cannot make someone feel good or have fun as instructors, but we can make it a nice experience by relaxing and enjoying ourselves [11]. A connection between the student, the teacher, and the classroom must be made. In higher education, students have the chance to develop personal relationships with their instructors [8].

Tews et al. [77] asked students to rank the aspects of their education that they enjoyed the most in order to find ways to make learning fun in college lectures. The most rated category was humor. Bringing humor into the classroom has a good effect on creativity and the generation of new ideas [7]. However, it is not always easy to achieve. Students' creativity was inhibited when they were in an environment where their lecturer or supervisor made them feel frightened or afraid, according to research done in an architectural design studio [73]. A positive classroom environment encourages a better attitude toward learning and increases students' motivation to study.

Considerations:

Establish a fun, dependable, and exciting environment where people feel "safe to fail" [35]. Give students the freedom to try out ideas without fear of repercussions. Icebreaker activities help people develop their personalities, create a relaxed environment, and set the stage for future collaborations. Perhaps have folks "draw the globe" [24] or make a self-visualization. Additionally, you could play games like the Graphic Continuum "Match It! Game" [71] or Charty Party [44].

4 CREATIVITY IN CONTEXT

Watching a cookery show inspires you to bake. Attending a craft show could provide you with ideas. Context is essential to the creative process. Context in creative pursuits refers to everything that surrounds the activity. For instance, from the actual creative process (physical [49], social [2]) to the data visualization design process, which includes the context of data collection. We can consider any circumstances and settings that around the main topic or action, as well as any environments and situations that influence it without being it. They can be implicit or explicit, known or unknown conditions, in addition to cultural, situational, spatial, social, political, material, economic, environmental, emotional, institutional, geographical, and ideological objects and/or phenomena. Context is an important factor to take into account while organizing creative activity. Data selection, creator motivation, visualization ideation and authoring, public and audience perception and reception, and access to different ideas and resources at different stages of the creation process, including interactions with a variety of stakeholders, are just a few of the aspects of the creative process that are impacted by decisions. Through quick tasks, students can explore this important relationship between data collection and visualization. For example, they can employ methods proposed to assess possible visualization tools while data is not yet collected [48].

- Data is impacted by context. Decisions about what is measured and recorded have an impact on how we interpret, represent, and evaluate data [18,23,27,28,32]. In addition to recognizing issues with the data, students can gain from exercises that promote data contextualization by considering how other influential factors, such ethical considerations, might be portrayed. For example, design students were required to create data-stories about Toronto to facilitate communication with persons impacted by this data. We had students create data sheets for their data sets, even if stakeholders would be involved, particularly in larger classrooms [31]. By actively engaging with the social and physical fabric of the city, students were able to put their study into context and personalize the data analysis. By encouraging an awareness of situations that were not there in the digitally downloaded data, it frequently prompted them to reconsider their focus and approach their data storytelling efforts in a different manner.

- In another case, context not only conveys relevant information but also elicits an emotional response.

Huron et al. [41] held a physicalization creation workshop at the Design Research Society conference during the 2015 European Union (EU) refugee crisis. Two participants provided a physicalization of a paper chain, with each human figure on the chain representing an asylum applicant (Fig. 3). "They are your obligation now," they asserted passionately as they displayed their efforts. Every element of the event, including the participants' creative process and delivery performance, the organizers' choice of the dataset to publish, and the public's response, was impacted by the setting, which resulted from the migrant crisis. Considerations:

• Consider both the contexts of the activity itself (such as the media, datasets, audiences, and expectations) and the contexts of the creative process (such as the activity's time and location, the surrounding circumstances, social pressures, and cultural conditions) when designing an activity.
• Provide free-form activities that let people explore a variety of contexts (e.g., social, environmental, political, cultural).

• Participant diversity can support the creative process when activities are examined and critiqued from a range of contexts and viewpoints.

5 PROVIDING FREEDOM TO ENCOURAGE CREATIVITY

Allowing students to choose what and how to create their visualization representation concepts is one way to foster their creativity. When teaching students how to create and construct data visualizations, it is critical to respect and encourage their originality. For instance, we experimented with a free-form data visualization training style as novice data visualization educators. We outlined the course using the "Design Study 'Lite' Methodology" [75]. Although this was the first time this course was offered in an engineering department in this style, students from all backgrounds or disciplines were able to enroll in our data visualization course, select their own dataset and target audience, and select acreating a platform for creating a creative data visualization. Throughout the semester, we gathered unofficial student input regarding their educational experiences. We share our ideas and lessons gained based on the comments we have gathered and our own observations. Students from various fields, such as Human-Computer Interaction, Data Science, and Medicine, registered for the course even though it was taught in an engineering department. Students from various fields were able to contribute their distinct viewpoints to class discussions because of this. flexibility in the choice of data. For their course project, students had the choice to use their own data. They then selected a range of statistics, including research project outcomes, job performance data, and data pertaining to entertainment and leisure. Students said it was valuable to be able to select a dataset that interested them since it allowed them to be creative and provide a unique visualization that went beyond the representations that were previously accessible.adaptability in choosing an audience. Students stated that they may target their visualization design for audiences other than their peers by having the opportunity to select the audience for the data visualization. For instance, one student decided to create a data visualization for individuals with a fear of flying that shows all air flight incidents during the last century. They wanted to demonstrate how rare flight accidents are. According to some students, displaying their study data helped them express their ideas more clearly and share significant findings with classmates and supervisors.No matter their level of programming experience, students may learn and use visualization techniques because to the flexibility in the tools chosen to create the visualization systems. Based on their expertise and abilities, students choose Tableau Storyboard, Python, JavaScript, and D3. Thus, students might concentrate on creating imaginative data visualizations rather than learning how to code. To support every student's choice, it can be challenging to present different developing platforms in the classroom.

Considerations:

• A student-centered approach can increase students' ownership of the activity by allowing them to make their own decisions.
• Peer-to-peer comparison of methods and solutions can enhance class discussions and foster innovation by allowing students to learn from one another.
• Creating more creative visualizations is made possible by granting flexibility in target audience, data

selection, and tool choice.

- It is important to consider and support the instructors' increased workload when granting these liberties, especially when it comes to student evaluation.

6 DIFFERENT LEARNING MATERIALS FACILITATE LEARNING

Learning necessitates intricate and frequently irregular developmental phases. Designing data visualizations requires creativity, which may be supported and learning facilitated by using a variety of materials. Other materials, such as cardboard, paper, pens, plastics, LEGO bricks [85], cards [40, 71, 72], other tangible objects, or even people, can be used to accommodate different learning styles and comprehend data visualization processes from various angles, in addition to the standard digital resources used when teaching visual activities, such as a computer, phone, or tablet. These kinds of techniques are also frequently employed in workshops devoted to creativity and invention (see design thinking) [85]. A vast array of teaching strategies are also available, including experience-based learning, narrative, comics, active learning [13], deconstruct/reconstruct methods [58], and many more. Multimedia presentations, for instance, stimulate meaningful learning and active cognitive processing [55].The use of various materials has numerous advantages. Chen et al.'s findings [21] demonstrate that a range of physical items' material attributes (colors, densities, weights, lengths, forms, and so on)

encourage the process of creativity. The extensive possibilities of digital visualization tools in the early stages of the design process can frequently impede students' creativity, particularly in visualization education. This obstacle is reduced when designing with LEGOs, and it has been demonstrated that students are more open to revising their initial concepts, leading to the production of final designs with excellent visual quality [62].

There are obstacles and difficulties. Some students disregard the creative process in favor of focusing only on honing their coding skills and getting directly into the raw facts [63]. However, some pupils are hesitant to use materials that they believe to be out of the ordinary. By introducing sketching exercises (like the Five Design-Sheets method [63,64] or making data comics [81]) in problem-solving classes on the design process of data visualizations, students can process their data in a variety of creative ways and learn more about it by discussing their sketches with their peers.

Considerations:

- To guarantee their success, a polite and understanding classroom setting is required, where students can be inspired to experiment with different approaches and embrace originality in their ideas.
- The dynamics of the student group can have a significant impact on how effective such tactics are. As a result, considerable time may need to be devoted to things like easing pupils' anxiety about sketching "poor" pictures and encouraging them to be receptive to criticism.
- Additionally, it is critical for instructors to feel at ease with their teaching methods.

7 DEBATE AND DISCUSSIONS

The debate and discussion of visualization constructions, best practices, and methodology may pique participants' interest and encourage them to learn about visualization concepts, techniques, and unresolved issues within the framework of participatory visualization activities.

Academic visualization research includes intense debates and discussions that might be incorporated into the classroom. Examples include the usage of rainbow colormaps [15], ChartJunk [14, 29], 2D versus 3D visualizations, the advantages of pie charts, and biased visualizations [76]. At workshops like IEEE VIS's VisLies and AltVis, where alternative visualization projects can be discussed, numerous cases have been recorded. Furthermore, in a number of fields, including the political, social, and educational sciences, debates have been suggested as a teaching method [59]. At workshops like IEEE VIS's VisLies and AltVis, where alternative visualization projects can be discussed, numerous cases have been recorded. Furthermore, in a number of fields, including the political, social, and educational sciences, debates have been suggested as a teaching method [59]. They serve as a calculated tool to get pupils interested by challenging conventional wisdom, examining opposing views, and encouraging critical thinking. Students are not required to possess any particular background or prior knowledge in order to participate in the process. As an alternative, participants can conduct research on the argument, synthesize their own views, and compare and contrast various points of view, which ultimately can boost creativity and pique interest in learning more about the subjects at hand.

Students may find learning new ideas difficult or uninteresting at times. According to prior teaching experiences, peer-based conversations have a good effect on participants both during lectures and asynchronously through online discussions [26]. For instance, with the help of the VisGuides [25] discussion platform, we have engaged in debate and debates at the University of Zurich for the past three years. People can share ideas and ask inquiries on the site. It creates a substantial corpus of evidence supporting various viewpoints. Increased engagement in lectures, critical thinking exercises, curiosity to learn more about the subjects, and awareness of the current visualization issues and open problems were some of the advantages noted and surveyed by the participants following the course.

Considerations:

- • Participants should be given tools and training, such as guidance on general debate protocols, content analysis, and explicit debate or discussion goals, prior to debating visualization concepts or guidelines.
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- • Arguments and conversations ought to be backed up with facts. As long as they add to the conversation, we take into account evidence from both peer-reviewed journals and other unofficial publications found on websites, blogs, and forums.
- • Discussions or arguments may have an open-ended conclusion. For example, unresolved issues, fresh application scenarios, or proof of applications, restrictions, and clarifications, among other things.

8 THE NEED FOR A SKETCH

A creative design process is supported by sketching, which also externalizes ideas, records ideas in a common format, helps validate excellent (or terrible) ideas, and can be used as part of an evaluation submission process.

To demonstrate the difficulty, students found it difficult to consider options without sketches. In our example, students with a background in mathematics and computer science were asked to make a dash-board based on data on air quality in several cities over a number of years. It was necessary for their dashboard to provide various visualizations that interacted with one another. They could choose which data features to show, what kinds of visualizations to use, and what kind of interaction to offer (see Sect. 6's freedom/choices and Sect. 10's comfort-zone). However, many students had to choose between many visualizing methods, such as a scatterplot, line chart, or even a geographic visualisation. They posed queries such "how to incorporate temporal or spatial data," "what interaction procedure would be ideal for a user," and "how should the visualisations be arranged?" They concentrated on analytical elements because they had a background in mathematics and computer science (business). Making a sketch has a significant impact. They developed, discussed, and continuously refined their design concepts even while they were only using crude, extremely preliminary sketches. To create and enhance a visualization design, they experimented with color combinations, sized and positioned various elements, and looked at the wider picture.

Bonnici et al. [12] shown that participants experienced less difficulty and better functionality in their results when they were permitted to sketch throughout several trials using visualization-related applications. Regarding data intake, Walny et al. [80] demonstrated that participants had more in-depth observations and inquiries regarding the data they were examining when they connected sketches to datasets and represented the data in pictorial drawings. Sketching can be used in design in a variety of methods, including the Five Design-Sheets technique [64], online sketching [19], data comics and storytelling workshops [6], and critical thinking sheets [66].

Considerations:

• Students should understand that their sketches have no right or incorrect answers. Supporting their creative process is the aim (assuming any design structures, such the Five Design-Sheets, are adhered to).

• Students who have a knack for programming will find that sketches made without a computer [65] let them focus on the design phase and push execution to the side.
Students should be encouraged to discuss and debate their sketches. Additionally, this can aid in the future development of sketches.

9 STEP OUTSIDE YOUR COMFORT ZONE AS A CATALYST FOR CREATIVITY

"Where the magic happens" is well outside of "your comfort zone," as we sometimes hear or see in Venn diagrams. Activities that push the learner beyond of their comfort zone in terms of the tools they are permitted to use, the instructions they may trust, the resources they are given, and the limits they must meet are a way to encourage the development of creative thinking skills in students. According to our experience, one of the biggest barriers to innovation in visualization is the desire to use conventional computational tools like Tableau or D3 to transform a given spreadsheet of data into a visual representation of these data—possibly because people think this is what is anticipated, or perhaps they are unaware of alternative methods. However, this method is rather restrictive because, in most cases, the final visualization is (i) primarily based on the spreadsheet's limited data and (ii) limited by the learner's technical proficiency and the visualization tool's expressive capabilities.

Changing the parameters in which students are expected to approach visualization design is one way to push them out of their comfort zone. Eliminate the conventional dependence on predetermined expectations that characterizes a normal data science course. An activity that asks you to "imagine the ideal visualization on a topic of your choice" is one technique to do this. Students are encouraged to create imitation perfect data tables from scratch and must presume that they have access to the best data available to convey their message. Without computers, they must use paper sketches to carry out their ideas. These exercises could expand upon or enhance earlier thoughts and concepts, including Freedom (Sect. 6). For example, removing restrictions on data quality and availability, tool capabilities, and technical skills should encourage creativity. However, as many students tend to rely on well-known chart and map designs because that is what they know best, these strategies may not be enough to foster innovation. Here, students gain from being given yet another set of restrictions, such as updated guidelines or design constraint flashcards, which force them to completely reevaluate their solution and so foster their creative juices. For example, students can be given a predetermined color scheme, a different target audience, or a different media (e.g., a poster for non-experts versus a mobile phone app for domain experts). They can also be advised that "color is not allowed: transmit the same idea without color."

Considerations:

• While removing data and tool constraints expands the possibilities for learners to explore what is otherwise not possible, such freedom can leave learners feeling lost. • Giving students complete agency over the choice of topic that aligns with their values can increase engagement and build learners' resilience through a sense of purpose [82], which results in improved learning. Think about giving students who are more confused resources to help them get started, including a list of data repositories and seed ideas or themes like "visualization for social benefit."

• Sketching intimidates a lot of kids. Consider complimentary activities that allow students to practice sketching while also understanding that professional drawing skills are not always necessary to convey ideas in an enjoyable manner, since this can help alleviate poor confidence in drawing abilities [63].

10 CONSTRAINTS AS SCAFFOLDING

limitations since scaffolding can be useful. They can be beneficial and foster creativity. It can be challenging, for instance, to ask kids to compose a short story on a blank sheet. However, it is a different matter entirely to ask someone to write a novel in which they are the main character and have a superpower that they lose at the age of 18. The outline provides structure, establishes a particular frame of mind, and enables the participant to dive right into the narrative. Because it eliminates some of the unknowns from the creative process, it can foster innovative thinking. People may feel uneasy and unsure of what to choose when presented with an excessive amount of options. When faced with a design challenge and a blank sheet of paper, people may be afraid to make the initial impression [64].

However, a thorough explanation of the procedure is required. The Five Design-Sheet method, which divides the creative issue into five sections each with five pieces, is how we teach visualization to undergraduate students [63]. A sped-up recording of the entire five-sheet creative process is played as a remedy. By showing a videotaped example of someone performing the procedure, it aids in its explanation.
The creative process has several facets that can be scaffolded. A few instances have already been presented in other sections. For example, we may limit the materials used to make the visualization (Sect. 7) or mandate the usage of specific colors, which might force people to step outside of their comfort zone (Sect. 10). In another example, we scaffold the entire creative assessment by breaking it down into steps using the Explanatory Visualization Framework [67] (see building blocks, Sect. 3). Other scaffolds might be taken into consideration, like emphasizing the student's goals or rewards or encouraging participation in a public competition [52]. A few things to think about are: • Consider the structures that can be used to the creative process.

• Ensure that the scaffolding is discussed in detail; you might want to use movies to illustrate the procedure.

11 DISCUSSION

We have only touched on a few of the potential factors. Our concepts are only a small portion of the results from the Dagstuhl seminar. They serve as a foundation for developing a more comprehensive set of visualization principles for instructional creativity. They offer concepts, insights, and tactics that others can adopt. What is the key takeaway from combining all of these concepts? What are the broad factors that individuals should value?

Make well-rounded decisions. There are too many options for us. There are several alternatives available to us, ranging from drawing on paper, using real objects, to scripting data-to-visual mappings that enable the automatic plotting and re-plotting of millions of data items. Different approaches allow for different kinds of audiences, activities, and learning goals. As a result, depending on their circumstances, educators must decide on their learning objectives, assignments, material, and unit structure. The amount of time we (as teachers) have allotted, the number of students enrolled in the course, the presence of a lab assistant, and other factors must all be taken into consideration while making decisions.

Be picky. We are not advocating for teachers to adhere to every rule. Teachers, students, researchers, and designers must choose what works best for their particular circumstances. One individual will not be able to incorporate all nine concepts into their instruction. Furthermore, expecting pupils to learn everything in a single course is not realistic. The science and practice of visualization are quite diverse. It includes a wide range of elements, including technical abilities in computer science and engineering, methods and techniques borrowed and modified from psychology, sociology, and human-computer interaction, and principles derived from empirical research and theories in cognition, perception, information science, and design.

selecting a tool. When creating activities and assessments for a particular audience, teachers frequently find it difficult to decide which visualization authoring techniques and tools to use as learning support tactics. One of the key choices that determines how creativity and visualization design are taught is selecting the appropriate programming language. Although computational solutions like D3, R/ggplot, or Python are very strong since they offer both expressiveness and reproducibility, their steep learning curve necessitates the integration of programming training to teach these languages or the establishment of strict prerequisites. More approachable wrapping libraries like Observable [17], Vega [70], or Processing [30] are examples of lightweight computational solutions that enable the development of programming skills covertly [20] while lowering the bar for inexperienced learners. Although programming offers greater flexibility and autonomy than template-based tools like Tableau, it still necessitates that students possess a strong computer literacy and/or that teachers dedicate a portion of their curriculum to teaching programming. Ideally, educators should aim for authoring strategies that have a low threshold [57], meaning that they require little or no prior knowledge or experience, and a high ceiling [57], meaning that they provide tools that enable visualization creators to achieve both expressiveness (through design flexibility) and efficiency (through automation, replication). Regardless of the approach, the instructor must feel at ease.competent with the concept, informed about the subject, and assured with the methodology

non-computer instruments. In our reflections, we emphasize the importance of employing non-computational tools like sketching (Sections 9 and 10) and building blocks (Section 3), which are simple to use, do not require any prior knowledge, and are entertaining and playful (Section 4). In addition to being great ways to encourage students to be creative (anything is possible when sketching), these are also very effective teaching tools that let students concentrate on the visualization concepts rather than the difficulties of carrying out a big idea.

Technical skills should also be taken into consideration by teachers. Low-tech methods like sketching and drawing might not scale up and might not be as well received in some professional contexts. By defining data-to-visual mappings, students who are interested in learning about visualization frequently anticipate and are keen to learn how to use computing libraries and toolkits that facilitate data manipulations and automated rendering. In our experience, it is challenging to teach both visualization science (i.e., cognition, perception, theory, creativity, narrative, etc.) and deep technical training (i.e., teach JavaScript+D3, or R+ggplot+Shiny) in a normal self-contained course that consists of twelve classes. In order to support programming teaching, current options required the instructor to either forgo technical training or limit access to a tech-savvy audience, or to forego creative and critical thinking exercises. We still lack a clear solution that is appropriate for a wide audience, valued and used in industry, and supports teaching of the entire range of learning outcomes in the field, even though visualization researchers are still pushing for authoring methods and tools that further bridge the gap between free-form creative sketching and powerful, reproducible data-to-visual mappings [69], such as investigating approaches like lazy data binding [47, 51, 84, 86].

Think about the learner, the learning path, and the learning objectives. In order to teach principled approaches to visualization design, the instructor must work with the students to apply what they have learned [3]. Although this is true for any module, students who are unwilling to attend class for any reason—possibly because it is a requirement of their course—may be less interested and less likely to think about innovative and alternative teaching methods. However, difficulties in adult learning and higher education arise at all levels. As early as in elementary-level curriculum, previous research has described the absence of specific visualization requirements [22]. Poor vision literacy in the general public can be attributed in large part to unclear learning objectives and instructional aims [16]. The resources available to visualization instructors are crucial because, aside from drawing inspiration from previous course offerings by colleagues or from visualization textbooks like Munzner's [56], these resources generally lack learning objectives, exercises, and activities. Activities have the potential to empower underprivileged communities and act as an agent of inclusion. Lastly, we hope that this article serves as another source of inspiration, but we emphasize that the community must really define and compile a common set of high-level learning objectives to direct the creation of curricula.

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