Worksheets for Guiding Novices through the Visualization Design Process

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Abstract

For visualization pedagogy, an important but challenging notion to teach is design, from making to evaluating visualization encodings, user interactions, or data visualization systems. In our previous work, we introduced the design activity framework to codify the high-level activities of the visualization design process. This framework has helped structure experts' design processes to create visualization systems, but the framework's four activities lack a breakdown into steps with a concrete example to help novices utilizing this framework in their own real-world design process. To provide students with such concrete guidelines, we created worksheets for each design activity: *understand*, *ideate*, *make*, and *deploy*. Each worksheet presents a high-level summary of the activity with actionable, guided steps for a novice designer to follow. We validated the use of this framework and the worksheets in a graduate-level visualization course taught at our university. For this evaluation, we surveyed the class and conducted 13 student interviews to garner qualitative, open-ended feedback and suggestions on the worksheets. We conclude this work with a discussion and highlight various areas for future work on improving visualization design pedagogy.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—User-centered design

1 Introduction

To teach design in data visualization, educators combine many foundational components, from user interface principles [25] to data and encoding taxonomies [19]. Additional pedagogical materials for the field focus on visual or perceptual principles [3,26,27] as a basis for creating and judging data visualizations. Educators may also apply these principles and techniques in the classroom through the use of design critiques or a cumulative project. These visualization projects can be guided by several textbooks that expound upon different design processes [25,27] or design decision models [19] to help novice visualization designers learn how to effectively and methodically build and validate visualization systems.

Many of the pedagogical approaches to the visualization design process, however, are theoretical in nature. From our own combined teaching experiences across 13 courses, we have witnessed students struggle to incorporate these theory-based design concepts in practical, hands-on projects. As such, we believe there is a need for new approaches to teaching the next generation of visualization designers, equipping them with not just theoretical knowledge but also the practical steps for building better systems and tools.

In our previous work [15], we introduced one such theoretical model of the design process with four design activities: *understand*, *ideate*, *make*, and *deploy*. Each activity includes a goal, produces a visualization artifact, and provides a plethora of design methods to choose from. We found, however, that the theoretical framing of the model restricted and limited its use and actionability for novices, such as in the classroom or for class projects. To address these limitations, we crafted design worksheets with steps to assist students walking through the visualization design process for the first time. We validate the use of these worksheets with 13 students in a graduate-level visualization course. In this paper, we present the design activity worksheets — concrete steps for students to walk through the process of designing visualizations — along with an initial evaluation of the effectiveness of these worksheets, highlighting their strengths and limitations.

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2 Related Work

For the past few decades, pedagogy for data visualization and human-computer interaction has begun to shift from academic or theoretical foundations toward including skills for design, critique, and critical analysis [10, 11, 20, 23]. Educators have come to realize that they must rapidly adapt their teaching methods to the growing body of diverse students [6, 21], from flipped classrooms [10, 21] to online environments [2]. A recent approach among educators is to employ active learning [2, 8, 11], where techniques and methods are used to encourage deeper analysis and synthesis as opposed to just passively observing a lecture [2]. Active learning can help overcome some of the challenges faced by educators when teaching concepts surrounding design thinking [4, 10], such as creating divergent ideas [22]. For example, VizItCards [10] was created to help students practice and reinforce visualization concepts during workshops. Other active learning approaches include the use of data visualization exercises [14], rich discussions [5, 13], design workshops [10, 12, 29], design studios [9, 20], and design games [8].

Within data visualization pedagogy, guidance for how to design data visualizations is missing clear steps for novices. When teaching data visualization design, educators often incorporate user interface principles [25], taxonomies of data and encoding [19], ideal visual principles [3, 26], perceptual principles [27], and generally empower students with the ability to evaluate, criticize, and judge data visualizations. These concepts are often then applied in the classroom through critiques or projects [7]. Cumulative projects typically require students to acquire their own datasets, come up with ideas to visualize data for different tasks, and build an interactive, multi-view visualization system. Students may conduct their own design process according to design models provided in textbooks [25, 27] or research papers [19, 24], but often these models are terminology heavy, not actionable, and theoretical in nature. For students, it is often useful to have a clear set of guidelines or instructions to walk through this process for the first time. However, no such step-by-step guidance currently exists for the data visualization design process.

Educators have worked on concretizing steps for the ideation process. Specifically, the five design-sheet methodology [22] utilizes worksheets to structure and guide visualization students through the ideation process. This approach by Roberts et al. was evaluated with 53 students as a way to encourage engineering students to think divergently and creatively and sketch out ideas on paper when first designing a visualization. However, in a workshop at the 2016 IEEE VIS Conference that used these worksheets, we experienced a limitation: many steps must occur first, such as data collection, identifying the challenge, focusing on a target user, and finding tasks. Hence, in a workshop or classroom setting, this ideation step often happens too soon in the design process. Roberts et al. elude to these limitations as preparation steps [22], but these steps can be nontrivial and tricky for students. Thus, it would be beneficial to establish and evaluate more worksheets beyond just ideation for data visualization design pedagogy.

3 WORKSHEETS FOR THE DESIGN ACTIVITY FRAMEWORK

The first contribution of this work is the creation of design worksheets that follow the design process and decisions illustrated by the design activity framework [15]. Here, we discuss our process behind creating these teaching materials and provide examples of their use. The worksheets and teaching materials are located on a public-facing website[1] for their dissemination and use by others, and we encourage feedback and improvements to these teaching materials by other visualization educators over time.

Inspired by the five design-sheet methodology [22], we wanted to integrate the visualization design process into visualization design worksheets to enhance the teaching of a visualization design process. Our first goal was to create a worksheet for each of the visualization design activities: *understand*, *ideate*, *make*, and *deploy*. We wanted to provide example methods and tips to enable students to go through a visualization design process in its entirety. In order to create these worksheets, we reflected on our combined 23 years of experience creating data visualization tools and systems.

The primary author of this work coordinated the first draft of the worksheets, by reflecting on his own experiences learning data visualization design in course projects and applying this design knowledge across four design studies. He was also inspired by the use of related worksheets by a colleague running design studios in our university's architecture and design department. As a result, he pinpointed distinct methods for generating and evaluating visualization artifacts in each design activity. When identifying these methods, we knew that engineering-type students could benefit from focusing on creating many types of visualization artifacts, so we utilized the first four steps of each activity for generation. For example, the *ideate* sheet uses three sketches for concept generation as in the five design-sheet methodology [22].

We iterated upon the description of these steps and methods for each worksheet, and we presented the worksheets to our research lab to acquire additional feedback on their level of detail and utility. From this feedback, we received recommendations to place more of a focus on the users earlier in the process and to simplify complex, theoretical terminology, such as removing the use of the nested model [17,18] in the original design. Thus, the methods described on each worksheet were simplified and turned into a series of tangible and generalized steps, as shown in Table 1. We also walked through a previous project [16] using the worksheets to identify further elements to add: more helper text, warning icons, expected results for each step, and a label at the top for attachments. Lastly, we created several introductory and template guides to help students fill out each worksheet, and we include these resources in the Supplemental Materials.

We introduce the first design worksheet for the *understand* activity in Figure 1. At the top of each sheet, we describe the desired goal and resulting visualization artifact or outcome for the activity. Each sheet can be numbered in the top-right for keeping track of order and for planning and retrospection. For each worksheet's five steps, we included additional text to help students find the answer and complete each box. We added warnings about when to jump back to previous boxes or worksheets, and icons to illustrate the expected type of answer for each box: a list, a sketch, or a table. Lastly, the bottom-right boxes point to the next potential activities of the visualization design process.

[1] Supplemental Materials can be accessed via: `https://design-worksheets.github.io`

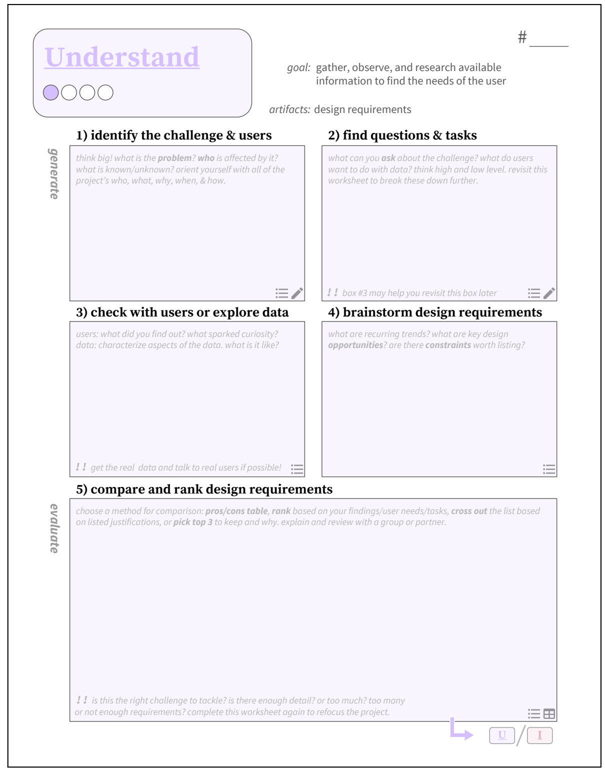

Figure 1: Worksheet for the *understand* activity. We tailored this worksheet to help students identify their problem, users, data, and requirements for a data visualization system. Full page printouts of all four worksheets are included in the Supplemental Materials.

4 EVALUATION METHODOLOGY

Before introducing design worksheets to students, we needed to form a basis of understanding, both in terminology and contextualized as a real-world visualization example. We created an 80-minute lecture on visualization design to teach the design activity framework [15] to 66 students in our university's graduate-level visualization course. This model was used to help categorize visualization artifacts and design decisions that were contextualized within a visualization design project, a cyber security visualization dashboard [16]. By utilizing this design study, we were able to explain the design process with actual, tangible concepts.

The lecture was followed by an in-class exercise that had students analyze and redesign an existing visualization using paper copies of the first two worksheets: *understand* and *ideate*. Additionally, we mocked up an example of how to use the design worksheets using the design study mentioned previously. An overview of this example is provided in Figure 2. As part of the course, students formed groups to complete a cumulative project: to design and build a web-based interactive visualization system. We recruited 13 volunteers from the course to complete the design worksheets for each of their six group projects, mentored by the primary author of this work. We also include a copy of all our teaching resources and project details in the Supplemental Materials.

The goal of this evaluation was to gain qualitative feedback on the worksheets rather than compare pedagogical effectiveness; however, we recognize a limitation of this methodology without a control group. We also had a limited number of student volunteers and time availability from the primary author, plus smaller group sizes are more manageable for qualitative methodologies. We were also striving to preserve fairness in the classroom, so all students had equal access to the volunteer opportunities, resources, and worksheets.

understand	*ideate*	*make*	*deploy*
identify the challenge & users	select a design requirement	set an achievable goal	pinpoint a target audience
find questions & tasks	sketch first idea	plan encodings & layouts	fix usability concerns
check with users or explore data	sketch another idea	plan support for interactions	improve points of integration
brainstorm design requirements	sketch final idea	sketching additional views	refine the aesthetics
compare & rank design requirements	compare & relate your ideas	build the prototype & check-in	consider a method to evaluate

Table 1: Five steps for each design activity. We break down each visualization design activity [15] into five concrete steps. The first four steps of each activity are generative, to establish design requirements, encoding and interaction sketches, visualization prototypes, or visualization systems. The fifth step is always evaluative, to compare different visualization artifacts in order to justify design decisions and record that reasoning down for later use. We shared these five steps with novice visualization designers, students, using design worksheets as a template, as in Figure 1.

Figure 2: Design worksheet examples. We created example worksheets using linked sketches from our BubbleNet dashboard project [16]. With this example, we taught students visualization design and showcased how a real-world, iterative design process can be captured using the worksheets. A detailed copy of each worksheet and all sketches are included in the Supplemental Materials.

For the cumulative projects, we provided the worksheets in both paper and digital form to all students, but only the 13 volunteers were required to submit digital or scanned copies of their worksheets as part of their project. One student was not part of the original volunteers, but due to complications with her project she reached out to the teaching staff for further help and guidance for visualization design within the context of her project.

To evaluate the efficacy of the worksheets in supporting the visualization design process, we collected data from three sources: a full-course survey, a focused survey on the worksheets, and interviews with student participants to elicit in-depth worksheet feedback. Additionally, the mentor met weekly with each group to provide feedback on their design process and on the worksheets. These meetings provided a basis for obtaining in-person observations, in addition to the feedback acquired anonymously through the surveys and detailed interviews. The questions and prompts we utilized are included in the Supplemental Materials.

The full-course survey was designed to gather anonymous feedback and assess the general utility of the design worksheets for teaching the course. Specifically, we asked questions about students' comfort level with design before and after taking the course along with which factors taught them how to design visualizations: lectures, in-class exercises, design worksheets, and the cumulative project. In the focused survey for those who used the design worksheets, we asked which worksheets worked well and which ones did not, and why, along with 10 questions about the usefulness of the worksheets. To avoid positivity bias, these questions varied between positive and negative wording.

After the student projects were completed, 11 students, at least one from each project, participated in a semistructured interview to provide feedback on the visualization design worksheets. The interview questions focused on digging deeper into the survey findings. We asked open-ended questions to gather suggestions for improvement. Lastly, we asked students to briefly describe steps of the visualization design process in their own words.

5 Evaluation Results

For the full-class survey, we received 25 responses. Twenty-three students showed an improvement in their comfort level for visualization design, on average 2 out of 5 points higher by the end of the course. Students ranked these improvements based on where they learned how to design, which was primarily through the lectures, projects, and class exercises. The design worksheets received a significantly larger portion of neutral responses for helping students learn, possibly because only some students used them in their projects. We compared the ratio of agreement to disagreement of these materials helping students learn. The design worksheets were on the level of other methods utilized in the course: design worksheets (13:1), lectures (23:1), exercises (20:2), and projects (18:2).

For the survey sent to the students who used the visualization worksheets, we received a total of seven responses. Overall, *ideate* and *understand* worksheets were selected (six and four students, respectively) as the most helpful design worksheets. Students stated that the *ideate* worksheet helped them critique their own designs, and *understand* helped jumpstart a visualization project. As stated by students, *ideate* *"is the most clear worksheet"* and *"critique of one's own design was most helpful"* and that both *understand* and *ideate* worksheets *"helped to get the project off the ground."* On the flip side, the *deploy* worksheet was selected (four students) as the least helpful, because students often did not have sufficient time to focus on this activity. Additional feedback highlighted some drawbacks to the worksheets, such as vague terminology or phrasing, creative limitations, and not enough structure. To uncover more information, we conducted interviews as a follow-up.

During the follow-up interviews, all students described the design process using elements of the visualization design activities. Specifically, four students correctly recalled the names of each visualization design activity, but four other students were unable to recall the *deploy* activity — possibly since most groups did not go through in this activity. As in the survey, all students found the *understand* and *ideate* worksheets the most useful since they forced them to consider different tasks, users, and ideas. Students noted that the worksheets provided a structured way to organize and compare notes about different visualization design artifacts. Three students stated that the worksheet example visualization project was helpful in illustrating how to use the design worksheets. Nine students followed a design process informed or exactly prescribed by the worksheets. One group acknowledged that their design process, while different, still adhered to the steps provided in each visualization design activity. Another student recognized the flexibility of the worksheets: *"If I had a different project, I would use each box in different ways depending on the context"* (participant #8, or P8).

All students agreed that evaluation was a necessary and important step for visualization design in order to pinpoint flaws in their understanding of the problem, users, tasks, interactions, and encodings. Through evaluation, one group discovered that their project was better suited to a subset of users, and another group realized that a particular encoding resulted in points overplotting. All students agreed that worksheets helped them document and organize their visualization design process. These design worksheets served as a *"snapshot in time"* (P1) and were sufficiently detailed to explain their design process for the final project report. Eight students described an iterative process that occurred, although informal and not written on any of their worksheets. Furthermore, the activities helped guide students as novice designers, such as one student who used the visualization design worksheets for the first time later in the course of the project and stated that *"When I used [the] worksheets it kept me focused on what I was doing and trying to get more ideas or more [encodings]"* (P8).

An intriguing finding was that four students employed the worksheets in surprisingly creative ways. For example, one student loaded the *ideate* worksheet in PDF form on her tablet and zoomed in to sketch various aspects of her visualization design, allowing her to expand and use more space for the visualization sketches. Also, another detail-oriented student transferred the design worksheets into textual form, listing all of the steps and hints, so that he could brainstorm and add detail to the problem and requirements over time, as a living document. Four students expressed frustration with the paper worksheets because they preferred another format, whether digital, larger paper, or the ability to structure their notes how they wish. As one student put it, *"I think the concepts are very helpful in the worksheets .... [but] for a free form thinker ... if you box it in then it is sort of restricting your creativity, as it tells you how much you have to fit into where"* (P9). Students suggested improvements and other feedback, which we explore next.

6 Discussion

To address these restrictions mentioned by that last student, a key improvement recommended by five students was to convert the worksheets into a step-by-step list, the same as the steps shown in Table 1. Based on the interviews, we recommend two formats for guiding the visualization design process: a list and worksheets. The worksheets provide structure, *"it's like a checklist to make sure everything is covered"* (P11), but they also limited free-form thinkers: *"if you have a lot of things on your mind, you won't fit everything in the box anyways"* (P6). Some visualization designers recommend paper for sketching [22], but others in the design community argue digital sketching can have functional benefits, such as shapes, undo, layers, duplication, and manipulation of details through zooming [28], which two students utilized and felt was vital to their visualization design process. An intriguing suggestion was to transform the worksheets into an app: *"a clickable, interactive worksheet, where you click on this [and] it will connect you with the other worksheet and have a screenshot"* (P8).

Students also suggested adding more worksheets to the materials. Six students felt that *"those [four] activities frame the process well"* (P2). However, two students brought up a crucial aspect of evaluation and feedback: that it might be worthwhile to devote a whole worksheet for evaluation, otherwise *"If you have it on the other worksheets, [evaluation] doesn't seem to have as much value"* (P10). Four students requested a visualization design worksheet to help probe into and explore the dataset or datasets that a group may want to visualize. By providing guidance, steps, and questions on aspects of the dataset, potential issues with visualizing the dataset could be avoided later, and such issues occurred in three student projects. Lastly, three students requested a visualization design worksheet on how to structure the code of a visualization system, particularly in the case of one group with no computer science background. Such a resource would help students brainstorm on how to structure classes in their code, especially for building data visualization systems.

Furthermore, some minor tweaks can be made to improve the visualization design worksheets. Five students noted that having a good student example of the worksheets would have helped define clear expectations for their work. We also received recommendations to use a date-field rather than a blank number-field to encourage students to simply organize their group worksheets over time as the numbers were not often used and harder to coordinate among group members. Students also suggested that each worksheet use a date-field rather than a blank number-field to more easily coordinate work as a team. Most students did not understand or use the helper text, result icons, and warning tips, so these should be clarified and revisited in future work.

Nevertheless, the design worksheets helped guide students through actionable steps for visualization design and facilitated effective discussions both within a group and with their mentor. As students highlighted: *"you break down the process into those clear steps... an intuitive flow"* (P2), and: *"this was really good guidance for us ... well categorized for the beginner"* (P3), and: *"I didn't know where to start. It was nice to have steps along the way"* (P4), and the benefit of generating ideas: *"we considered more options than we would have"* (P1). Despite the many improvements that can be made, we emphasize that the worksheets provided benefit to students, and a variety of future work could measure this success more rigorously and compare how usable and effective these worksheets are for students learning the visualization design process.

7 Conclusion & Future Work

In this paper, we have introduced design worksheets to guide and teach novices the process of designing a visualization system. These worksheets were designed to simplify the theoretical concepts of the design activity framework [15]. We include all of the materials we used to teach these concepts to 66 students in a graduate-level visualization course. We evaluated the use of the design activities and worksheets through surveys and interviews with 13 students. The results highlight what worked well and what could be improved on these design worksheets going forward. Lastly, we summarized these improvements and areas for future work on teaching visualization design to novices.

These design worksheets are one possible step toward building more effective teaching tools for data visualization and design, but plenty of work lies ahead. One clear area for future work involves materials for design inspiration: from visualization encodings to abstractions to tasks. Initial work shared by He and Adar in Vizit Cards [10] is a step in this direction, and we encourage the community to continue this line of work. While one student used VizIt cards, she would have liked to see the cards generalized for other visualization challenges. Furthermore, the design process steps and guidance can always be improved to be more descriptive, more clear, sufficiently succinct, and encompass other design methods and methodologies. Other common methods for teaching are design studios [10] and exercises [1], and it would be worthwhile to adapt design worksheets for these settings.

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References

[1] E. Bertini. Teaching — Information Visualization. `http://enrico.bertini.io/teaching/`, 2017. Accessed: 2017-02-03.

[2] J. Beyer, H. Strobelt, M. Oppermann, L. Deslauriers, and H. Pfister. Teaching visualization for large and diverse classes on campus and online. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[3] A. Cairo. *The Functional Art: An introduction to information graphics and visualization*. New Riders, 2012.

[4] K. Cennamo, S. A. Douglas, M. Vernon, C. Brandt, B. Scott, Y. Reimer, and M. McGrath. Promoting creativity in the computer science design studio. In *Proceedings of the 42nd ACM technical symposium on Computer science education - SIGCSE '11*, p. 649. ACM Press, New York, New York, USA, 2011. doi: 10.1145/1953163.1953344

[5] B. Craft, R.-m. Emerson, and T. J. Scott. Using pedagogic design patterns for teaching and learning information visualization. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[6] G. Domik. A data visualization course at the university of paderborn. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[7] M. Eggermont, C. Perin, B. Aseniero, and R. Fallah. Leveraging biological inspiration in an information visualization class. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[8] A. Godwin. Let's play: Design games and other strategies for introducing visualization through active learning. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[9] S. Greenberg. Embedding a design studio course in a conventional computer science program. In *Creativity and HCI: From experience to design in education*, pp. 23–41. Springer, Boston, MA, 2009. doi: 10.1007/978-0-387-89022-7_3

[10] S. He and E. Adar. VizIt Cards: A card-based toolkit for infovis design education. *IEEE Transactions on Visualization and Computer Graphics*, 2017. doi: 10.2450/2013.0043-13

[11] M. A. Hearst. Active learning assignments for student acquisition of design principles. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[12] S. Huron, S. Carpendale, J. Boy, and J. D. Fekete. Using VisKit: A manual for running a constructive visualization workshop. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[13] A. Johnson. Teaching data visualization in evl's cyber-commons classroom. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[14] A. Kerren, J. T. Stasko, and J. Dykes. Teaching Information Visualization. In *Information Visualization*, pp. 65–91. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008. doi: 10.1007/978-3-540-70956-5_4

[15] S. McKenna, D. Mazur, J. Agutter, and M. Meyer. Design activity framework for visualization design. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2191–2200, 2014. doi: 10.1109/TVCG.2014.2346331

[16] S. McKenna, D. Staheli, C. Fulcher, and M. Meyer. Bubblenet: A cyber security dashboard for visualizing patterns. *Eurographics Conference on Visualization (EuroVis)*, (just-accepted), 2016.

[17] M. Meyer, M. Sedlmair, P. S. Quinan, and T. Munzner. The nested blocks and guidelines model. *Information Visualization*, 2013.

[18] T. Munzner. A nested model for visualization design and validation. *IEEE Transactions on Visualization and Computer Graphics*, 15(6):921–928, 2009. doi: 10.1109/TVCG.2009.111

[19] T. Munzner. *Visualization Analysis and Design*. CRC Press, 2014.

[20] Y. J. Reimer and S. A. Douglas. Teaching HCI design with the studio approach. *Computer Science Education*, 13(3):191–205, sep 2003. doi: 10.1076/csed.13.3.191.14945

[21] P. Rheingans. Minor adventures in flipped classrooms, team-based learning, and other pedagogical buzzwords. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.

[22] J. Roberts, C. Headleand, and P. Ritsos. Sketching designs using the five design-sheet methodology. *IEEE Transactions on Visualization and Computer Graphics*, PP(99):1–1, 2015. doi: 10.1109/TVCG.2015.2467271

[23] H. Rushmeier, J. Dykes, J. Dill, and P. Yoon. Revisiting the need for formal education in visualization. *IEEE Computer Graphics and Applications*, 27(6):12–16, nov 2007. doi: 10.1109/MCG.2007.156

[24] M. Sedlmair, M. Meyer, and T. Munzner. Design study methodology: Reflections from the trenches and the stacks. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2431–2440, 2012.

[25] B. Shneiderman and C. Plaisant. *Designing the User Interface : Strategies for Effective Human-Computer Interaction*. 2004.

[26] E. R. Tufte. *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, CT, USA, 1986.

[27] C. Ware. *Visual Thinking: for Design*. Morgan Kaufmann, 2010.

[28] J.-C. Wu, C.-C. Chen, and H.-C. Chen. Comparison of designer's design thinking modes in digital and traditional sketches. *Design & Technology Education*, 17(3):37–48, Nov. 2012.

[29] A. Zoss. Challenges and solutions for short-form data visualization instruction. In *Pedagogy Data Visualization, IEEE VIS Workshop*, 2016.