VizItCards: A Card-Based Toolkit for Infovis Design Education

Shiqing He, *Student Member, IEEE*, and Eytan Adar

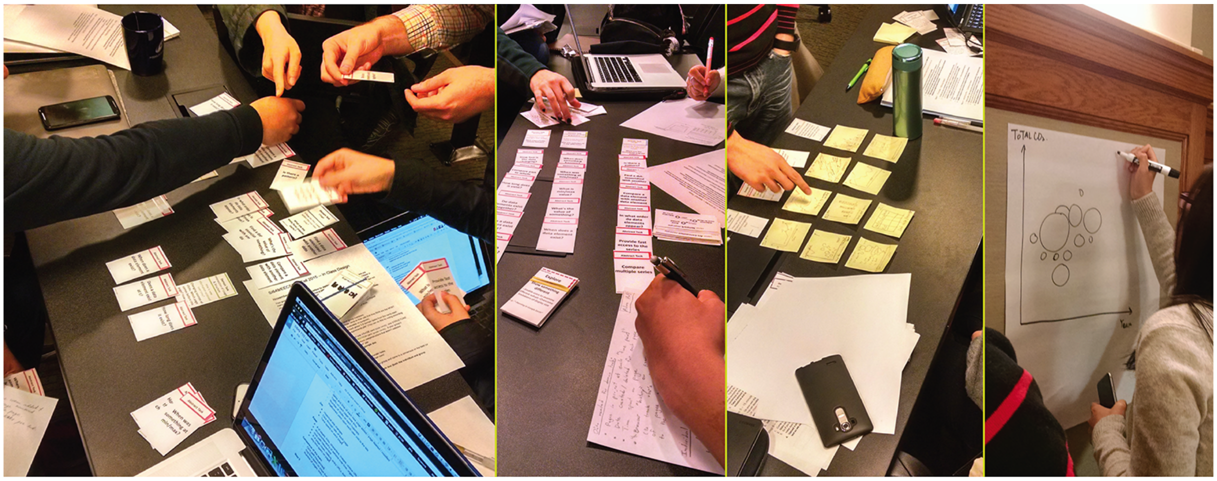

Fig. 1. VizItCards sessions in progress. From left to right: mapping abstract cards to domain task; grouping tasks; comparing individual 'mini-sketches'; generating a final, collaborative visualization.

Abstract—Shifts in information visualization *practice* are forcing a reconsideration of how infovis is *taught*. Traditional curricula that focused on conveying research-derived knowledge are slowly integrating design thinking as a key learning objective. In part, this is motivated by the realization that infovis is a *wicked design* problem, requiring a different kind of design work. In this paper we describe, VizItCards, a card-driven workshop developed for our graduate infovis class. The workshop is intended to provide practice with good design techniques and to simultaneously reinforce key concepts. VizItCards relies on principles of collaborative-learning and research on parallel design to generate positive collaborations and high-quality designs. From our experience of simulating a realistic design scenario in a classroom setting, we find that our students were able to meet key learning objectives and their design performance improved during the class. We describe variants of the workshop, discussing which techniques we think match to which learning goals.

Index Terms—information visualization education, peer learning, toolkit, card, design workshop

1 Introduction

The *practice* of information visualization design has evolved to the point where it is necessary to reexamine infovis *education*. Specifically, the nature of infovis design has shifted due to factors ranging from a more diverse population of practitioners (not just computer scientists), to a wider array of easy-to-use tools (e.g., D3), to a broader demand for infovis solutions. It is now not only possible, but broadly expected that "bespoke" infovis solutions be deployed in varied settings. Standard curricula, focused largely on leveraging research-based knowledge, are often insufficient in covering important aspects of practice. Other engineering disciplines have come to terms with the fact that practice often involves complex dependencies, multiple stake holders, and difficult trade-offs that are not often covered in standard curricula [59]. Additionally, the concept of infovis as *wicked design* [6] is becoming more prevalent, but strategies to contend with broad design challenges are not as common as one might hope [29]. To enhance our pedagogical toolkit in light of these evolving education needs, we have developed a card-based workshop, VizItCards, that is intended to structure a design exercise in a classroom context.

• *Shiqing He and Eytan Adar are with the School of Information at the University of Michigan, E-mail: {heslicia, eadar}@umich.edu*

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Our motivation in designing VizItCards is that *design thinking*, the conception and planning of the artificial [6], is a necessary feature of an infovis curriculum. The most apparent need for this approach is the "wickedness" of the underlying problem: the problem may be unclear until a solution is devised; a stopping rule is unavailable– one must work towards satisficing; though solutions can be better or worse, they are rarely right or wrong; and each solution is unique and novel [54]. In addition, a practitioner must often take into account the collaborative nature of design, the reality of multiple stakeholders, economic and social limitations of implementation and adoption, the "political" nature of information, and many other concerns that fall outside of the technical curriculum. Broadly, design thinking allows us to address, "a common complaint: that the most important areas of *professional practice* now lie beyond the conventional boundaries of *professional competence*" [59] (emphasis ours).

VizItCards are implemented in a workshop structure that guides students through a design experience. Small groups work to isolate *domain tasks*, *data needs*, *design alternatives*, and *evaluation* of design decisions. Each run-through of VizItCards is intended to focus on a particular topic or topics that are often derived from the curriculum. For example, if the topic is hierarchical visualization, the workshop specification might be to visualize a tennis match. The workshop participants utilize VizItCards to identify a key set of tasks they want to support (identifying a small subset and isolating coherent use cases using *domain cards*). They can then determine their data needs before proceeding to an exercise of rapidly sketching design alternatives. Sketching, which is done both individually and as a group, is a task supported by *layout cards* (specific encoding techniques) and *inspiration cards* (high level infovis concepts intended to "trigger" ideas). Finally, the group evaluates their final design in various ways– by either comparing to other groups or to "professional" solutions (they will only see these professional solutions *after* completing the workshop). At each stage, students justify their design decisions and refine choices made in earlier steps. This provides an opportunity for reinforcing core curriculum concepts (e.g., providing the perceptual justification of a particular encoding design).

Unfortunately, adding design thinking into a course further exacerbates the wicked nature of *curriculum design*. Ten to fourteen weeks of a quarter or semester do not often afford flexibility in incorporating new materials. Class time is already saturated with lectures on perception, color, data modelling, design heuristics, interaction, specific visualization techniques, collaborative visualization, storytelling, and many other topics. Time outside class is often allocated to readings or long-term projects. An ideal solution would not force an undesirable trade-off in teaching core topics and supporting our new learning objectives. In our design of the VIZITCARDS, our intention was to specifically engineer it to support multiple goals. First, we designed it to support an immediate practical exercise of material learned in lecture and readings. Second, we wanted to organize the VIZITCARDS workshop so that the students would experience a micro-instance of design experience that is as real as possible but can be modified to emphasize different learning objectives. Different stages can be extended or removed and the workshop itself can be played "forward " (where the input is a design problem and the outputs are visualizations) or "backwards " (where the inputs are visualizations that are deconstructed to identify key benefits and limitations as well as application areas).

We have taken the opportunity in creating VIZITCARDS to apply a number of educational innovations and design science results. For example, a VIZITCARDS workshop is collaborative in nature and uses a small group (4–6 students) structure. Beyond the scaling benefits for large classes, collaboration of this sort has a number of pedagogical advantages. First, infovis design in practice is often a collaborative experience [37], where a group of people attempt to construct and maintain a shared conception of a problem [15, 56]. Visualization collaborations often take place among data scientists, domain experts, designers, and researchers. To collaborate efficiently, team members need to have clear understanding of common goals, and actively participate in the exchange of information and ideas. Though it is difficult to simulate this range, a group of students is more likely to do so than an individual. When properly navigated, these diverse perspectives can lead to better design outcomes [50]. Second, the collaborative setup of VIZITCARDS is designed to encourage peer-learning [5]. Peer-learning, and variants such as peer tutoring, cooperative learning and peer collaboration [13], have been demonstrated to have benefits such as introducing unique motivational and cognitive benefits for peers, boosting self-esteem, enhancing scholarly achievement and fostering pro-social behaviors [12]. Finally, working with groups allows us to use rapid and parallel-prototyping strategy in the workshop. Recent experimental work (e.g., [19, 20]) has demonstrated the effectiveness of this approach in generating better designs.

The VIZITCARDS module has been implemented in a large graduate course at the University of Michigan. The workshop idea has evolved and been refined over 8 semesters (the first instance was in January of 2010). In this paper we describe the VIZITCARDS implementation, which we believe capture the best of what we have learned. We demonstrate how VIZITCARDS can be adapted to different scenarios, learning objectives and educational configurations. We report on our experiences with VIZITCARDS in classes as well as in a more controlled workshop. Our students told us that they thought the workshops were one of the best features of the class. During the workshops, we observed the students generating design solutions that matched well to complex and realistic problems we had set for them. Our hope is that other educators will adapt the design of VIZITCARDS and create alternatives that can better address the shifting objectives of infovis education. Cards and other workshop materials are available at `http://vizitcards.org`.

2 RELATED WORK AND DESIGN INSPIRATION

We briefly review pedagogical practice and design models that inspire our approach. Additionally, we summarize other card-based design workshops and highlight those that motivated our design.

2.1 Pedagogical Practices

Information visualization education has evolved significantly over time. Original concerns of whether formal visualization education is warranted [16] (broadly, yes) has made way to concerns of what an infovis curriculum should contain [28]. As new courses were developed, it was possible to identify key learning objectives and techniques that were consistent across visualization courses broadly, and infovis specifically [29, 35, 36, 49, 57]. Often such courses adopted large group-based projects as key features of the class. However, these were largely deployed as single instances of standard engineering problems, a strategy that is often unsuccessful in addressing wicked design concerns. In particular, because each design instance is unique, practice with multiple problems is highly beneficial.

Infovis education has certainly not stagnated. New appreciation for inter– and multidisciplinarity have led to appreciations (and problems) of diversity of expertise in courses [17, 21]. Others have found ways to integrate realistic, but controlled, problems into their courses [64] and new mechanisms to provide feedback on designs [30]. The VIZITCARDS workshops are consistent with these pedagogical trends and can be used alongside these approaches. Critique [38], in particular, connects infovis to the studio practice in HCI. The suitability [66] and effectiveness [22, 52] of studios has long been appreciated in HCI, and the relationship to infovis courses is apparent. A broader acceptance (and demonstrations of effectiveness) of lecture alternatives in CS—including studios, and peer and collaborative learning [7, 23]—has made it possible to integrate novel modules.

2.2 Design Frameworks in Infovis

In order to best simulate infovis design processes, we have leveraged recent work that identify key workflows and effective strategies. Work in this area falls into two general areas: ways of structuring designs and ways of designing.

The *Four-level Model* was initially proposed by Munzner [47] for structuring infovis design "layers" and validity threats. The model has been extended to understand the connection between layers and offer guidelines to designers and educators [45, 60]. Roughly, the four decision-making levels include: (1) domain problem characterization, (2) data / operation abstraction design, (3) encoding / interaction technique design and (4) algorithm design. In VIZITCARDS we have utilized the first three layers to structure the workshop phases.

A number of recent research efforts have sought to identify the structure of the infovis design process. Sedlmair et al. proposed a nine-stage design study framework where designers complete the design in nine interconnected steps [60]. McKenna et al. combined the nested model with a creative design framework to support more flexible design processes [44]. The work proposes a way of classifying design strategies based on *understand*, *ideate*, *make*, and *deploy*. These four high level categories can be used to classify different design methodologies and we apply them in describing VIZITCARDS as well as other design "games" below.

The four-level and nine-stage frameworks align closely with other general HCI design models such as the the Design Innovation Process Model proposed by Kumar [39], and the five-design phases described by Martin and Hanington [26]. The work by McKenna et al. [44] identifies other design methodologies (adapting many of the HCI techniques) and describes their possible in the context of infovis design. Of specific interest to infovis is the Five Design Sheets Methodology [55] that structures the design process. VIZITCARDS offer a different way of working through design, but the high level structure is consistent with these various workflows. Our belief is that a student practiced

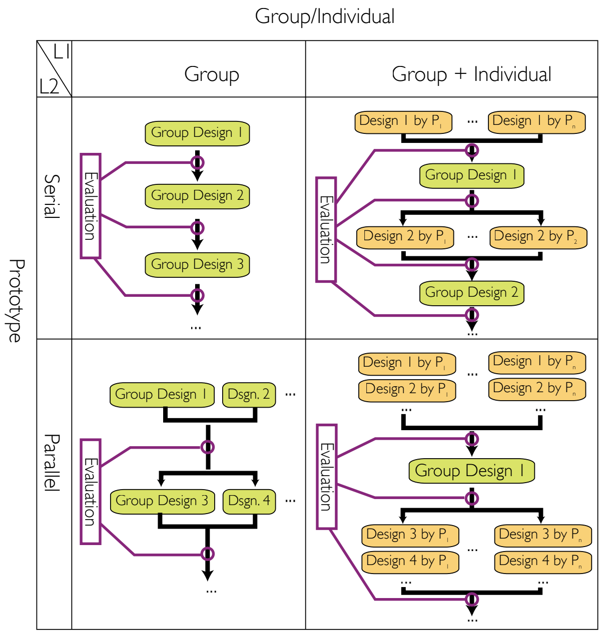

Fig. 2. The two-level decision model for collaborative schemes illustrating the role of the individual vs. group and parallel vs. serial design

with VIZITCARDS should be able to adopt alternatives more easily, and those experienced with related techniques should find it easy to use VIZITCARDS. Methods such as affinity diagramming, card sorting, colleges, and design charettes and workshops are among the most related (see [39, 44, 55] for a summary of these and others).

2.3 Collaborative Design

Collaborative infovis design, like other collaborations, can involve different patterns. Based on studies of different collaborative schemes (e.g., [9, 19, 20, 24, 37, 40, 41]), we are particularly interested in those patterns that can (1) drive diversity in the solutions and (2) encourage peer-learning and engagement by all team members.

We broadly find two key decision points that can impact these outcomes: the role of the individual versus the group and serial versus parallel design. Various combinations of these facets yield the configurations illustrated in Figure 2. Other workflows are also possible, such as individual-only workflows, but these are inconsistent with our high-level goals as they do not encourage collaboration or peer learning. At different points in the workflow a design or designs can be *evaluated*. This evaluation may take the form of discussion within the design group or external validation (e.g., presenting to "clients" or domain experts). Serial evaluation involves only considering the merits of one design relative to itself. In contrast, parallel evaluation allows for evaluation of different alternatives relative to each other.

A *group–serial* solution (upper left cell) has the group creating a solution together, evaluating it, then iterating on the design. Because of team dynamics, such solutions may mean that one or a few individuals dominate the design and a local "maxima" is reached–one that is less optimal (possibly as a consequence of group-thinking). In contrast, a *individual+group–serial* solution (upper right) has each member creating alternatives *independently*, then combining these through collaboration. After evaluation, this process can be repeated to refine the design. The advantage of this approach is that diverse solutions can be generated and all group members can present their alternatives. A further refinement is the *individual+group–parallel* (bottom right) which allows an individual group member to generate multiple designs on her/his own. This has the benefit of multiplying the options considered and ensuring that individuals do not fall victim to their own local maxima. Design studies [19, 20] suggest that parallel prototyping improves outcomes, exploration, sharing and group rapport. We

Mechanics	Range	Example	Learning		Designing				
			Terminology	Technique	Define	Explore	Concept	Evaluation	Launch
Simple	Generic	PLEX Card				●	●	●	
↓	Specific	77 Cards	●	●	●	●	●		
	Generic	THINKPAK		●		●	●	●	
Complex	Specific	VizItCards	●	●	●	●	●	●	

Fig. 3. Examples of card-based design toolkits described by purpose, application range, and mechanics.

mainly adopted the *individual+group* approach for the first decision layer, and tested both serial and parallel prototyping for the second decision layer.

2.4 Design Toolkits and Games

Our choice of a card–based toolkit for infovis is inspired by other design-focused card decks. The tactile nature of the cards and the ease by which they can be organized or browsed is attractive as this can encourage use and collaborative activities (see Figure 1). Simultaneously, cards are often understood as "games." Since games have *mechanics*, or rules that structure "play," we can leverage this notion to enforce a particular structure on the workshop. Note that with the initial implementation of VIZITCARDS we do not focus on competition–a feature of many traditional gamifications. We collected and surveyed over twenty card-based toolkits and observed three main features:

Purpose: The general purpose of design-aid toolkits is to assist design in different contexts. A closer look reveals that toolkits can be learning-oriented, design-oriented or a combination of both. *Learning-oriented* cards assist users to master terminologies or techniques, reinforce design process, and encourage the practice of certain techniques (e.g., [14, 48, 58, 69]). *Design-oriented* cards assist with specific design tasks (e.g., furniture or game design) or design facets (e.g., eco-friendliness) rather than teaching terminologies and techniques (e.g., [31, 58, 69]).

Design-oriented cards are likely to assist some parts of the design process. We might, for example, classify these workflow steps using the *Universal Methods of Design* framework [26]: *Define* (define and agree the project parameters); *Explore* (study and synthesize domain information through immersive research); *Concept* (prototyping and solidfying ideas into deliverables); *Evaluation* (testing, critique, and feedback); and *Launch* (deploy maintain the launched product).

Applicable Range: *Generic* design toolkits can be used to assist design in a wide range of areas (e.g. [51, 48, 46]) whereas toolkits with *specific* applicable range are designed for a narrow field (e.g., [3, 11, 14, 42, 58, 61]). Decks such as PLEX Cards [41] (focused on "playfulness") lie somewhere in between.

Mechanics: Mechanics refer to rules by which the toolkit is used. Some toolkits are designed to be used freely, whereas others require users to follow particular sequences [67]. We are specifically interested in if, and how, the mechanics of the toolkit "simulate" the real-world design process. Most toolkits focus on smaller pieces of the design pipeline (e.g., ideation or evaluation) and simple "one-round" structures. Building a toolkit to support the entire process requires more complexity and might require users to iterate certain steps.

Flipping through a physical deck of cards might evoke the notion of play. In fact, many design toolkits are "playable" board or card games. Game mechanics such as role-play, reward, and competition, are often incorporated into these games (e.g. [31, 46, 61, 62],). We return to the notions of "playfulness" and competitiveness as there are often consequences learning objectives and outcomes.

Based on the three features we observed, we designed the VIZITCARDS as a mixed-oriented toolkit with complex mechanics that focus specifically on infovis. As shown in Figure 3, we aim to promote learning of terminology, technique, and simulating all stages of the McKenna et al. [44] design process with the exception of "launch."

3 SI649: INFORMATION VISUALIZATION

We briefly describe the context of the course in which we designed and implemented the VIZITCARDS module. While we believe that the exercise is generalizable and can be made to work in a variety of contexts, there are specific constraints imposed by the student population, course philosophy and structure, and our core learning objectives. Our choices in implementation are based (and constrained) by these features. In Discussion (Section 5.4), we offer suggestions for how the module may be modified for other situations.

SI649 is a graduate course with enrollment largely coming from Masters students in the School of Information at the University of Michigan. These students are predominantly from the HCI and Information Analysis and Retrieval (IAR) specializations. Because the class is an upper-level Masters class, the expectation is that most students have taken other HCI classes but this is not a hard requirement for the course. Students from other departments, including Computer Science, Architecture, and Art and Design, also register. In Fall of 2015 this course officially became cross-listed as a graduate course in CS and enrollment ramped up (around 25% of the enrollment). To ensure that the "studio" component of the course would not suffer due to the growing registration, enrollment was capped in each section at approximately 30 students. The course was either taught every semester or, as in Fall of 2015, two sections were offered simultaneously. The course has a fairly standard coverage of theoretical topics and was inspired by offerings in other schools (e.g., Stanford, Berkeley, Georgia Tech, etc.). Students have 3 hours of class time per week which is divided roughly into a 1.5 hour lecture and 1.5 "lab." Assignments range from short programming labs (roughly for the first 5 weeks), mid-size individual assignments (building an *explorable explanation*, i.e., interactive educational material, that uses visualization) and a large group-based client-driven final project. An example syllabus from 2014 is available at `http://si649.cond.org/?cat=42`.

3.1 Labs and Workshops

A key component of the course, since it's inception, has been the use of design workshops during lab time. Randomly assigned groups would work on a roughly specified problem during the one and half hour lab time. The design specifications are pulled from a paper or existing implementations that are relate to the topic of the day (e.g., tennis for hierarchical vis). However, students would not see the "solution" until they had completed their own designs. This was done explicitly to provide design practice but also to force students to work through the design constraints and trade-offs in the problem–that is, the "wickedness" of the application. This approach prevented students from critiquing (or more commonly, criticizing) the deployed solution without first considering the constraints. Students were tasked with creating a short presentation (5 minutes) on the "professional solution" for the next class meeting. A student was randomly selected to present and lead a discussion.

3.2 Learning Objectives

In designing lab exercises, a specific set of learning objectives were identified. Students should be able to:

- **Design**: generate a well-justified solution (sketch) that includes: (1) identify possible "domain tasks" and use cases, (2) determine which data is necessary to implement the solution, (3) determine good encodings (visual representations) for the data based on effectiveness and expressiveness criteria, cognitive and perceptual justifications, and HCI practice (i.e., around interaction)
- **Ideate and Compare**: identify the design space of alternatives and trade-offs between designs
- **Collaborate**: apply effective processes for collaborative work
- **Apply**: correctly apply new theoretical knowledge to designs
- **Synthesize**: extract generalizable ideas from new techniques

Pre-2014, we found the workshop structure to be highly popular and it allowed us to achieve many, but not all, of these learning objectives. Designs, in particular, were often done by intuition and solutions were not always justified. Because of this, students were not correctly applying theory or finding ways to generalize from existing visualization applications. Additionally, strong personalities within groups meant that collaborations were uneven. As a consequence, the design space was not fully considered. To fix these issues, we began to add worksheets in the Fall of 2014 that drove the design process more and forced students to better deconstruct their solutions based on the domain/abstraction/encoding criteria of the block model [45]. This improved designs at the group level but individual students' learning was still uneven and design alternatives were not often considered. VIZITCARDS are, in some ways, a culmination of the evolution of the workshops and was designed to more fully address the course objectives.

4 DESIGN VARIANTS

In the design of VIZITCARDS workshop, we have retained the high level design pipeline used in earlier versions of the course which roughly mapped to the top three layers of the nested model (domain, abstract, encoding). Each of these is implemented in a workshop *Component* (high-level design tasks). *Mechanics* represent different rule sets that help ensure that the tasks and learning objective are accomplished (e.g., each participant selects the top-3 domain cards independently, and a vote determines the top-5 domain tasks to pursue in the workshop). A workshop mechanic may be supported by one or more *Materials* (cards, worksheets, etc.). Taken together, it is possible to find a set of mechanics and materials that can produce a desired design workflow. The left side of Figure 4 is a superset of components, mechanics and materials that we considered in the design of VIZITCARDS. Depending on which learning objectives we would like to emphasize, different mechanics and materials can be combined to support different components:

1. **Domain:** analyze the target domain and agree upon a set of domain tasks that need to be performed (e.g., find the most, and least, visited web pages in the last week).
2. **Data:** gather and model the data that is needed for constructing the infovis (e.g., visits (quantitative) per web page (nominal)).
3. **Abstract:** map domain-specific tasks and data into more generic and abstract tasks (e.g., find the top– and bottom-k items in a list-based quantitative property).
4. **Encoding:** select graphical representation of each data point and arrange them in optimal ways (e.g., a sorted bar chart of pages and visits with an interactive slider to select k)
5. **Evaluation:** generate and receive feedback on the design to support further design and deployment decisions (e.g., determine the expressiveness and effectiveness of the solution from and absolute and relative perspective).

These components, coupled with the learning objectives, drive our selection of mechanics and materials. During Fall 2015, we began systematically exploring different workshop structures. We implemented six specific workshops (see Table 1) using four different variants (see Figure 4, right). Each workshop variant has its own advantages and disadvantages. Variant IV (see Section 4.5) reflects our "best" design, in that it balances competing learning objectives well. Nonetheless, there are advantages to the other designs which we describe below. Workshops 1–5 were run during the semester and workshop 6 was done after the semester (with past course participants).

4.1 Card Types

A consistent component across all workshop instances are the cards. VIZITCARDS workshops utilize four types of cards (Figure 5):

Domain Cards feature specific domain tasks and are uniquely constructed for each workshop. These tasks reflect what a domain user might do (e.g., finding the most visited web page). When appropriate, domain cards are further grouped (e.g., tasks focusing on single web page versus tasks that require comparing sets of pages).

Abstract Cards display specific actions that might apply to a given dataset. For example, abstract cards with "set operations" are good candidates for modelling the domain tasks of "SetVis" systems [2] (e.g., "find elements belonging to a specific set" in a Venn diagram). These cards purposefully do not use domain-specific terms and multiple abstract tasks can be "executed" to achieve a domain task. Specific

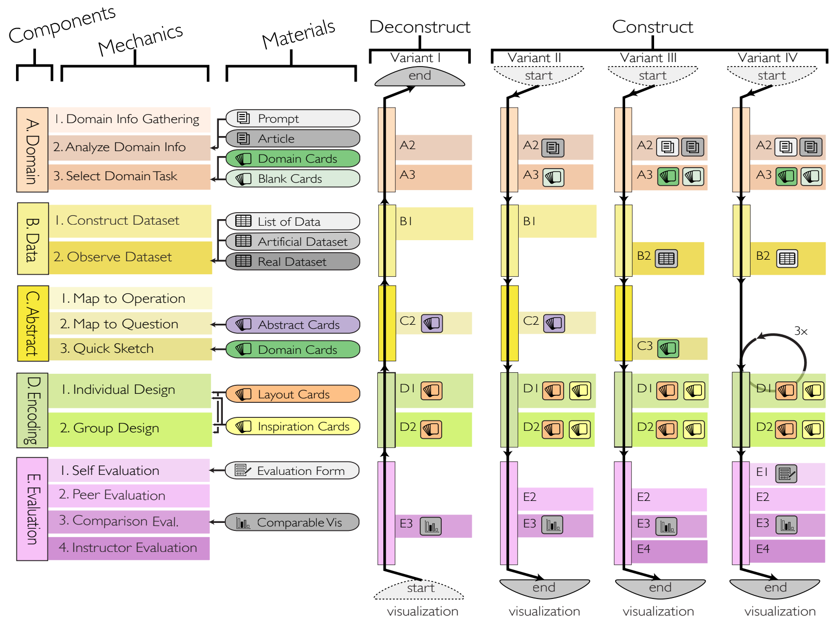

Fig. 4. Abstract structure of the VIZITCARDS workshop and variants. Five configurable components (A-E) are fulfilled by various mechanics (A2,B1,C3, etc.). Materials such as cards and evaluation forms support these mechanics. Four implemented variants (one deconstructive and three constructive) are displayed on the right.

encodings can be tested against abstract tasks for expressiveness and effectiveness (e.g., how well does the encoding support the task?).

Layout Cards contain different visual encodings. Simple examples like bar charts as well as more complex forms such as treemaps are represented in this card type. In selecting layout cards, we attempted to find representative encodings that "remind" the workshop participant of classes of encoding techniques. For example, we may not have a card for a *cushion treemap* but will assume that students will recall their existence when prompted with the general treemap image. To avoid limiting students to specific encodings, we designed the cards to textually emphasize the encoding components (e.g., bubble chart = size encoding+position encoding). We provided around 70 unique layout cards to ensure that a diverse range of examples are included.

Inspiration Cards contain conceptual triggers based on underlying perceptual, cognitive, interaction categories, and other high-level concepts covered in the course. For example, cards on pre-attentive processing, Gestalt principles, or specific interaction techniques (e.g., those based on [68]). Unique combinations of layouts and interactions may also be featured (e.g., dust-and-magnets). These cards are intended to be "thumbed through" to inspire new ideas as well as reflection on designs.

We had originally considered cards for the data and evaluation steps. However, in play-testing we found there was little debate about which data was needed for different tasks and a simple sheet was sufficient. Evaluation is largely done by comparing the abstract and domain cards or between the sketches and the task cards (i.e., is there support for tasks in the design?). Specific types of cards as well as specific cards can be brought in and out of the workshop based on the workshop's goals. For example, we avoided providing layout cards related to hierarchical structures before discussing hierarchical infovis. In this way, a "deck" may be kept to a manageable size.

4.1.1 Prototype Materials

In order to rapidly iterate on card design, and to support the changing domain cards, we used sheets of 2×3.5 inch business cards. To print the cards we created spreadsheets that had columns for the type of card, textual materials, and images. These spreadsheets were then "mail merged" using Microsoft Word into printable card templates.

Students were provided with one or more decks to be used in the workshop. Other instructional material and prompts were printed on

Summary of VIZITCARDS Workshops:

I/W	Topic	# Sktch.	EES
I/1	Two "set" vis chart comparisons [1]	NA	
II/2	Evolution of a website [8]	61	2.15
II/3	Tennis match [33]*	61	2.11
III/4	Plagiarism analysis [53]	198	2.38
III/5	Carbon emission [10, 27, 4, 63]	154	2.25
IV/6	Traffic information [34]**	34	2.63

Table 1. Workshops 1–5 (10 teams, 4–6 participants each, 3 members of the teaching staff); Workshop 6 (2 teams, 4 participants each, 1 teaching staff. Surveys were run after workshop *3 (33 responses) and **6 (8 responses). Sketch count includes total individual and group sketches. EES is an evaluation metric described in Section 5.1.

letter sheets (students were encouraged to scribble on and annotate these materials). Standard letter sheets (blank) and post-it notes were provided for individual sketches. Large, poster-sized, easel pads were given to groups (see rightmost picture in Figure 1). Permanent white boards were also available in the classroom.

Participants were instructed to document their process in a Google Document shared with all group members and teaching staff. As participants made decisions or moved between phases of the workshop they would take digital pictures of their materials (e.g., card piles), load them into the shared document, and create annotations/captions if necessary. This allowed them to document their work and return to their decisions when evaluating alternatives. Teaching staff could also monitor progress and identify possible issues during the workshop as well as providing real-time (digital and face-to-face) feedback.

4.2 Variant I: Visualization Deconstruction

The first workshop was conducted in October of 2015 (week 6 of the class). The curriculum had covered key theory (e.g., perception, design, interaction and evaluation) and the course switched to visualizations targeting specific data types (networks, hierarchies, temporal data, etc.). When presenting example visualizations our major learning objective was that students be able to find key features of these systems for generalization, i.e., the abstract tasks. The open-ended workshops we had run in past semesters did not provide practice in this area and

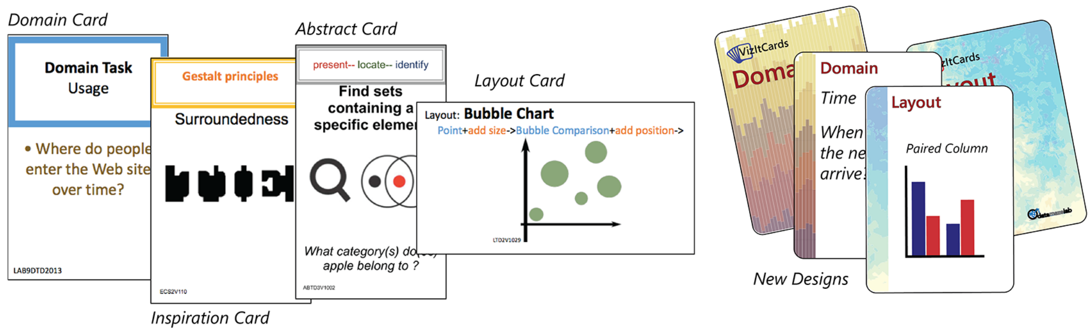

Fig. 5. Sample domain, inspiration, abstract and layout cards prototypes and refined versions

students had difficulty isolating abstract tasks and connecting them to domain problems or, conversely, to encodings. Our first workshop was designed to simultaneously address this learning gap and test our early card prototypes. This workshop variant is unique in that the design exercise worked "backwards". Thus, students were asked to *deconstruct* (i.e., reverse engineer) visualizations rather than to build them.

Task: We selected an *Euler diagram* and *Radial Sets* that were manipulated to have roughly the same expressiveness (adopted from [1], see supplementary materials). The workshop was structured to have groups work backwards from the visualizations to isolate what abstract tasks, data requirements, and domain problems each was useful for.

4.2.1 Mechanics and Materials

Step 1 Mechanics: Teams were instructed to first determine the encoding of the data. Given two visualization images, they were required to recognize the "meaning" of each mark and the type–nominal, ordinal, quantitative–of the data (a task to connect them to the Grammar of Graphics model [65]). This was done individually and then as a group. *Materials*: A worksheet with the visualization and "exploded" view where each mark was isolated was provided. Inspiration cards, specifically ones listing retinal variables (e.g., color, shape, etc.) were provided for reference.

Step 2: Abstract task cards were divided equally (and randomly) among team members (two copies of each card were provided). Given the data and image, participants were asked to determine which tasks apply to the given visualizations (i.e., expressiveness, or does the visualization support the task). A first "filtering" pass was done by each individual. Groups were then tasked with gaining consensus and ranking tasks based on effectiveness. *Materials*: Cards for this workshop corresponded to the 26 tasks described in Alsallakh et al. [2] and included tasks such as "find elements belonging to a specific set." Cards also contained a sample question that was representative of the task (e.g., "find all fruits" or "which element is green and red?").

Step 3: On completion of the workshop, students had to create individual presentations on the required reading and to specifically compare the tasks identified with the ones the authors emphasized [1]. Individual slide decks were graded and one volunteer student drove a discussion based on their presentation (students can volunteer, but if no one volunteers we select a student at random to present–thus incentivizing good preparation).

4.2.2 Feedback from Variant I

Judging from group reports, all teams successfully disassembled the encodings and conducted in-depth comparisons for the two given visualization. However (as expected), we found students had difficulty with the notion of abstract tasks. In part, some abstract tasks on our cards are necessarily vague. Thus, it was difficult for the groups to come to a consensus (on their own) about the meaning of a card. Though groups were largely successful in this, the step was time-consuming. Despite the challenge, we found that students had an increased appreciation for task-based thinking. They were able to compare the expressiveness (in this case, equivalent) and effectiveness of the different visualizations relative to how well each would support different tasks.

4.3 Variant II: Initial Toolkit With All Five Components

The second and third workshops tested VIZITCARDS with all components and serial collaboration (Figure 2, upper right).

Workshop 2: Workshop 2 ran during a week featuring temporal data and was based on visualizing the "evolution of a website" problem described by Chi et al. [8]. The paper conveniently lists a superset of domain tasks, only some addressed by the paper.

Workshop 3: Workshop 3 was implemented during the hierarchical visualization week and focused visualizing a tennis match [32]. The specification for this workshop left ambiguous the use case for the visualization (visualizing an ongoing game? is the tool for an avid tennis fan? etc.).

4.3.1 Mechanics and Materials

The teaching staff identified a set of domain tasks for each workshop and encoded these in cards. We designed 17 cards (in 3 high-level groupings) for Workshop 2, and 16 cards (in 4 groups) for Workshop 3. Based on the selected domain tasks, and different data-specific task-schemas we covered in lecture, we also constructed abstract cards for the workshops and expanded the Workshop 1 deck. Layout cards were expanded to include temporal and hierarchical visualizations.

Step 1 Mechanics: Each team divided the provided *domain task cards* (two of the same cards were provided to each group) evenly among team members. Each member picked 3 domain tasks that she or he thought were most important to the topic. The team discussed these choices and selected 3–5 design targets. We required participants to select domain cards from different high-level groups to ensure that tasks were sufficiently challenging. *Materials*: domain cards.

Step 2: Each participant generated a list of the data they needed to satisfy the selected domain tasks. The team then discussed the choices and arrives at a consensus. *Materials*: blank paper.

Step 3: Each team divided the *abstract task cards* equally among its team members (again, two of each card was provided to each group). Individuals filtered these, then participated in group discussion, to identify the abstract tasks necessary for the selected domain task to be achieved. *Materials*: abstract cards.

Step 4: Individual members sketched a visualization solution that best satisfied the domain and abstract tasks and then presents these to their group (one sketch per person). *Materials*: Blank sheets; layout and inspiration cards.

Step 5: After a group critique of individual sketches, the team began to develop a consensus solution (represented in a final sketch). *Materials*: Blank poster-sized sheets; layout and inspiration cards.

Step 6: After class, each participant was required to read the corresponding paper with the "professional solution," then compare and contrast their group's solution in a 5-minute presentation. Individual feedback was provided by the teaching staff, and all the designs (and feedback) were shared with the students (i.e., students could see all the designs and feedback in one place). As before, a volunteer or random student was selected to present and lead discussion during the next class meeting.

4.3.2 Feedback from Variant II

After Workshop 3, we designed an anonymous survey to check elements of our workshop design. Questions ranged from reactions to the course materials and mechanics as well as open ended responses. We received 36 responses (3 were discarded because the student hadn't participated in both workshops). Overall, students found the workshops to be a positive experience (31 answered very, or somewhat, positive for Workshop 1, and 30 for Workshop 2). We also asked participants to rate their experiences of using the cards specifically and 26 students strongly, or somewhat, positive for Workshop 1 and 24 for Workshop 2. Most students agreed that they benefited from the structure and their group worked better due to it (five students agreed, or somewhat agreed, that less would have helped their group–only one strongly agreed). The domain mechanic and cards were viewed as positive (29 somewhat, or strongly, agreed).

The data construction step was appreciated by 31 of the participants (2 neutral). Some participants pointed out that the familiarity with the background information is crucial for constructing or using the dataset, especially in the design challenges that require domain-specific terminologies. For example, Workshop 3 required participants to have basic familiarity with the rules of tennis, a problem for some (based on past experience with the task we did provide a rule sheet and ensured that each group had at least one person with tennis experience).

Step 3, the abstract card task, was the hardest and the least appreciated component in Variant II according to our observation and feedback survey. Twenty-six participants agreed or strongly agreed with the statement "finding a common set of abstract tasks/objectives is important." On the whole, this is encouraging. However, students observed that this was a highly time consuming activity. This task took away from iteration and consensus building time. We observed that many groups tended to map excessive number of abstract cards into a single domain task, which also increased the time taken to "evaluate" the designs. Overall students found the layout cards to be highly useful (27 strongly or somewhat agreeing). Many students also indicated that they would like their own decks.

Students indicated that time was a concern, something we recognized through observation as well. For example, time constrains meant that not all domain tasks could be considered in depth. This was particularly problematic for larger groups (of 5 or 6 participants, and in one outlier case, 7). We also observed that domain cards had good coverage but would occasionally limit participant ideas. As a result, we added blank domain cards to the next variant. It is also notable that earlier steps (such as domain task selection and dataset analysis) took more time than anticipated (e.g., 15 of 90 minute for selecting data–a task we anticipated to take about 5 minutes). In part, this was due to poor time management, but also the open-ended nature of some materials. In later VIZITCARDS variants we introduced more domain-specific information, explicitly used a timer to encourage switching steps, and provided easier to use materials such as a sheet of pre-seeded tabular or graphical representations of the data (students were asked to simply circle items on these sheets rather than generate them). We were generally satisfied with Variant II in meeting a number of our learning objectives but were somewhat disappointed that teams had insufficient time to produce a wide range of design alternatives.

4.4 Variant III: Quick Sketches

Based on the feedback from Variant II we implemented a number of small changes and one, more significant, mechanic change. Specifically, we replaced the abstract card selection task with a more informal mechanic that used rapid mini-sketches to generate possible design components and variants.

Workshop 4: Workshop 4, which came during a week on text visualizations, had the students construct a system for analysis of plagiarism (based on the work in [53]).

Workshop 5: In a week on storytelling in infovis, Workshop 5 was focused on building a narrative visualization to describe how different countries contribute to carbon emissions and the impacts of various agreements. We did not have a single specific solution in mind, but were inspired by a number of visualizations produced by major news venues around the time of the COP21 meeting in November of 2015 [4, 10, 27, 63].

New domain cards (23 for Workshop 4 in 3 types, and 17 for Workshop 5 in 4 types) as well as new layout and inspiration cards (based on lecture material) were created, and data sheets were pre-seeded.

4.4.1 Mechanics and Materials

Variant III largely followed the mechanics of Variant II but switched to structured datasheets for Step 2 and replaced Step 3.

Step 3 Mechanics: Students were (individually) instructed to produce a "quick sketch" for each domain card their group had selected (one sketch per domain card). The sketch was intended to be the minimal visualization necessary to address the domain task ("maximally" expressive and effective). *Materials*: post-it notes for the sketches (see Figure 1), and layout/inspiration cards.

For Workshop 5, students were allowed to compare their group's solution to any of the four narrative visualizations we used as inspiration. During the next class discussion four students described their group's solutions relative to the "professional designs."

4.4.2 Feedback from Variant III

Based on observations and materials we collected from the workshop participants, this variant produced more design alternatives. The quick-sketch mechanic received more positive feedback than the original abstract task mapping step. Students were forced to better understand the wickedness of multiple domain tasks as it was often difficult to directly integrate the "best" simple sketches into a single coherent visualization that addressed all domain needs. This required making trade-offs in interesting ways.

Unfortunately, the switch from abstract task selection to the quick sketches did not always save groups time and this cut into their work in generating individual and consensus designs. Larger groups in particular, tended to have long discussions. Each person had 3-5 quick sketches, resulting in up to 20 or more visualizations to consider. When running the workshop, we encouraged students to only pick 2-3 domain tasks each to generate quick-sketches for. Overall, this workshop design emphasizes the necessary trade-offs in selecting encoding but did not necessarily produce many design variants.

4.5 Variant IV: Parallel Prototyping

Work in collaborative design has demonstrated that parallel prototyping is an effective strategy [20, 46]. Design workflows that produce multiple designs and then receive feedback on them in parallel often outperform serial workflows (where individuals produce, and receive feedback on each in turn). Implementing this overall design required additional time. We recruited 8 students from the course to participate as members of two groups and paid each $20 for their time. We generated additional (illustrated) documentation and a walk-through to describe the workshop before students started.

Workshop 6 task: For this workshop we asked for a design of a traffic analysis system (inspired by [34]). The problem focused on public transportation and the uncertainty around departure and arrival times. Seventeen new domain cards (3 sub-types) were created.

4.5.1 Mechanics and Materials

To encourage additional thinking about domain tasks, participants were given a few minutes to generate their own domain cards to add to the deck used in step 1 (individually, and before seeing the domain deck). This was done, in part, to force participants to employ active reading when considering the specification (i.e., as a means for taking notes and synthesizing).

For Variant IV, we removed the abstract component to provide sufficient time for parallel sketching. Steps 4 and 5 were modified so that participants were asked to generate up to 3 individual sketches. These were discussed as a group and a *second* batch of individual sketches were generated. Each group generated 16 total variants (12 in the first iteration, 4 in the second), in contrast to the 4 of past workshops.

4.5.2 Feedback from Variant IV

In a second survey for Workshop 6 participants, 8 (of 8) graded the workshop as strong positive. Unfortunately 4 participants still felt that the workshop was still too short and indicated that 2.5 to 3 hours would be better. Participants agreed (or somewhat agreed) that they were able to effectively communicate their ideas and all ideas were heard. All eight also agreed that VIZITCARDS provided a common language (6 agree, 2 somewhat agree). Although it is difficult to arrive at general conclusions from 8 surveys, we note that participants consistently believed VIZITCARDS helped design a better final product.

5 WORKSHOP EXPERIENCES AND DISCUSSION

We describe both our experiences in running the workshops and metrics we devised to interpret their use.

5.1 Expressiveness-Effectiveness Score (EES)

Improving the overall quality of the students' designs was one of the main objectives of redesigning our workshop to use the structured format and cards. For the purposes of the design exercise, a "good" visualization is one that supports the domain tasks selected by the workshop participants (expressiveness) and does so well (effectiveness). In a sense, each team defines the objective. Successful learning, in part, requires that they meet those objectives.

To validate this, we defined a heuristic evaluation metric that we call the *Expressiveness-Effectiveness Score (EES)*. The score attempts to measure if the participants were able to encapsulate a specific domain task (effectiveness) and how well they did (roughly using the language of Mackinlay's APT [43]). Domain tasks (those we selected for the Domain Cards) are intended to be roughly "atomic" so it is easy to measure if they can be answered with the visualization (see the EES guide in the supplement for detailed examples). For each domain task selected by a group, we use the following rubric:

- *EES=0: information is not expressed in the design.*
- *1: information expressed, but requires significant effort to decode.*
- *2: information expressed, but requires effort to decode.*
- *3: information expressed and is easy to decode.*

One teaching staff graded each visualization relative to each domain task selected by a group (a task grade) and averaged those to provide a per-group design grade. This is not perfectly analogous to the APT definition as we do not consider redundancy in encoding (each task is considered independently) or over-expressiveness. However, we note that designs that are redundant or over-expressive can receive lower effectiveness scores as increased complexity can decrease readability.

For the five "constructive (build) workshops" (2–6), a teaching staff scored each team's design using the EES-based grade. Each design was considered independently relative to the domain tasks chosen by the workshop participants (scores summarized in Table 1). This roughly matches our expectations as Variants III and IV increased the number of design alternatives generated. However, it is worth acknowledging that students had become more practiced in design over time which may have contributed to the improved quality we found in their designs. In addition, the scores are influenced by the quality of the documentation as poorly documented designs might include confusing functions that lower the effectiveness score. Overall, our experience was consistent with past research on design where increased variant diversity through parallelism improves outcomes.

A reasonable question is whether VIZITCARDS improves EES over the more unstructured form. In Winter of 2014, 10 groups in a past iteration of the course participated in the "visualizing the evolution of a website" workshop (our current Workshop 2). In this workshop students were taught to generate domain tasks and were told to input those on their own (rather than using the cards). There was no specific requirement on generating design alternatives (though this was suggested). We reviewed the final designs generated in that workshop and found a mean EES of 1.71. It is difficult to completely attribute the improvement in EES to specific elements (mechanics or materials) in the VIZITCARDS workshop. However, we believe that the improvement demonstrates the usefulness of the structure in classroom settings.

5.2 Comparison of VIZITCARDS Workshop Variants

We briefly contrast the impact of different mechanics and materials of our workshop variants.

The **domain** component enforces the selection of domain tasks and defining use-cases. The most common mechanic used in our current variants is selecting from the domain task card deck (noted as *Select Domain Task* in the Figure 4). Individual selection of cards followed by a discussion functions well. This mechanic can be complemented by other such as *Domain Information Gathering* where the participants do their own data collection and use-case modelling (a potentially time-consuming process that we did not test) or *Analyzing Domain Information* where the teaching staff provides a high level specification which can be at different detail (we have selected high-level and unrestricted specs to emphasize the large decision space).

The **data** component ensures that students acknowledge which data they need to achieve their tasks. One mechanic has them generating this from scratch (*Construct Dataset*) whereas in other implementations (*Observe Dataset*) the participants are given sheets with possible data columns. The latter is more time consuming for the staff, but more effective for time-limited workshops. If a "data collection" learning objective is emphasized, the construction variant may be better.

In the **abstract** component, workshop participants produce more abstract tasks (e.g., "mathematical questions") that a viewer would execute to solve the domain problem. Variant mechanics include selecting from an abstract task card deck (*Map to Question*–which is costly in time for both students and teaching staff) and graphical sketches (*Quick Sketches*) that are single-task visualizations mapped to domain cards. Both have their own benefits. Selecting from the deck forces a deeper appreciation of what visualization afford and what tasks they are expressive/effective for. Quick-sketches provide a better appreciation of the wicked design problem and trade-offs on optimality. A third alternative, which we did not test, but considered, is one where tasks are modeled as computational questions (*Map to Operation*). We have also found that if time is limited, the component can be removed.

During the **encoding** part of the workshop, we have found it useful to use both individual and group sketches. If time allows, a parallel implementation (e.g., as in Variant IV) where individuals produce multiple individual sketches and iteration appears to produce better outcomes. Regardless of the number of sketches or iterations, each individual producing their own designs ensures both that free-riding does not happen and that alternative viewpoints can be considered during the collaborative steps. The layout and inspiration cards are useful for the purpose of ideation. We have found in previous years that workshop designs tended to look like the last system that was discussed in lecture. Flipping through the cards can break the "recency effect" and inspire conversation.

Finally, **evaluation** is a critical component. Self-evaluation can be useful to personally isolate limitations of ideas. Peer-evaluation allows for critiques from other viewpoints. Comparative evaluations (comparing a designed solution to competitors) is valuable to reconsider the entire design pipeline. Finally, instructor evaluation is provides critiques from an "expert" perspective. All evaluation modes have some value, and if time allows they can all be used. We believe that students who experience diverse evaluation modes will do better when it comes to their own projects.

5.2.1 Iteration Behavior

Real wicked problems cannot always be solved linearly and may require non-linear or iterative design [6]. However, workshops need to balance constraints (e.g., time, material, learning objectives) with realism. We have found that components/steps within our workshop, while adding some linearity, are crucial milestones to ensure progress. However, we do encourage students to revisit previous components (e.g., reevaluate domain tasks selected). We found that some groups decided to iterate over particular steps (e.g., producing over 25 mini-sketches instead of making individual sketches) or alter component order (e.g., identify data needs after selecting the abstract tasks).

The quality and diversity of the design alternatives are harder to assess in comparison to the quantity because within-person and within-group alternatives need to be considered. For example, in Workshop 6 (8 participants), 34 design alternatives (30 individual sketches and 4 group consensus sketches) were documented. Within one group (4 students), 13 individual sketches were significantly different from each other (the remaining six could be classified as highly similar). From a within-person perspective, two out of four students generated 2-3 similar sketches during the four sketch iterations while the other two participants created unique designs for each iteration (see supplement for Workshop 6 samples). Note that more diversity in design alternatives might not lead to better outcomes as groups can, reasonably, find ideas worth focusing on through targeted iteration.

5.3 Challenges

The structured version of the VIZITCARDS requires a number of trade-offs. First and foremost is the resource of class time. This is significant, and not every course can be changed to make time for this kind of structure. We used a "flipped lecture" structure to give us the time for the workshops and simultaneously ensure that materials were covered. We recorded a weekly lecture (usually 2-3 segments of 10-15 minutes each) that students must watch before class (a required, but easy, high-stakes quiz is used before every lecture to make sure students keep up with materials). A secondary benefit is that in-class lectures can now be moved to more active peer/collaborative-learning style. Though we believe that overall this has improved the course, this was nonetheless a costly preparation.

A second challenge is the amount of teaching-staff involvement in creating materials. Depending on the mechanic and cards used in the exercise, this can become a demanding exercise. Our hope is that by releasing VIZITCARDS, others will be able to create new modules that can be shared. While VIZITCARDS sessions can be run independently of teaching staff, we have found that engagement by instructors to be highly valuable. In our implementation, teaching staff take on the role of coaches [29, 59] during sessions. Because all teams work in a large room, the staff can wander between group and provide feedback, critique, and offer "prompts" to direct the group's attention to possible problems (for example, a visualization that may not scale), and to keep the workshop moving. The design specification for the workshop is often left intentionally vague to force the groups to make and justify choices. They often find it beneficial to describe their design to an external listener, even without getting explicit feedback. The teaching staff also benefits as we can ensure that learning objectives are being met by working with the students directly during sessions (and observing the changes to the shared Google documents). Things overheard in the workshops can also provide good material for discussion in subsequent classes. A vital step in the design process is providing feedback. Though students evaluate their own solutions, we have found that staff feedback is critical. For example, the staff critiques individual slide decks after the workshop (i.e., we comment on their self and comparative critiques). This ensure a positive and useful discussion in class.

5.4 Alternative Workshop Structures

There are a number of alternative structures to the VIZITCARDS workshop and we have described those we have experimented with above. Alternative structures may lead to other learning outcomes. For example there may be other "deconstructive" variants where existing visualizations can be broken apart. A variant we have considered is making homework assignments where students construct new cards based on their readings before attending class.

In constructing the VIZITCARDS workshops we play-tested a number of incentivized mechanics that would make the workshop more "game-like." Studies have shown that using game-design mechanics in non-game context has potential in encouraging positive learning behaviors in education within suitable context [18, 25]. However, building such games is not simple. In studying other design decks we found very few that offered both compelling (i.e., "fun") mechanics and were able to simultaneously achieve learning outcomes. The most common mechanic is of the form: place a problem card down on the table and have each play pick the best solution from their hand. If a player can convince the group their solution is best, they win. This approach is potentially fun for some, but certainly not universal–something of concern in a classroom. Additionally, this simple structure does not simulate a realistic design exercise. That said, we believe there might be pieces of the VIZITCARDS system that can be better gamified, achieving good outcomes for more constrained learning objectives.

We have begun to transfer our card designs to a more aesthetic form (see Figure 5 at right). However, we still find the business card prototypes to be a cheap and easy to produce format. It is certainly worth considering what physical forms cards should take and the trade-offs in cost. Another alternative we have considered is the use of a phone-app driven variant of the VIZITCARDS but worry that participants would lose the ability to organize and pile cards in a shared space.

Finally, though we have designed VIZITCARDS to be used in classroom, it is entirely possible that it can be used to structure real design exercises. We hope to be able to test it in those scenarios in the future.

6 CONCLUSION

In this paper we present VIZITCARDS, a toolkit that helps to structure collaborative infovis workshops in a class setting. VIZITCARDS workshop offers an adaptable design that can target different learning objectives. We describe our experiences with workshop variants and present alternative uses of the toolkit. Based on our observations, qualitative analysis, and participants' survey feedback, we find that VIZITCARDS structure collaborative design workshops in desirable ways that simulate the construction and critique of infovis designs.

We believe the VIZITCARDS produce powerful mechanisms for addressing the shifting demands of infovis education. As practice changes, the need for more design thinking is crucial. Specifically, practice with wicked design problems is vital as the need for bespoke visualizations increases. We offer the cards and guidelines for use in the hopes that they can be developed further by others.

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