RESEARCH ARTICLE

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Abstract

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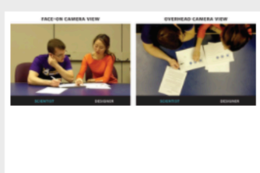
Figures



The Design Help Desk:
A Collaborative Approach to Design Education for Scientists and Engineers

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Abstract

Visual design, learning sciences, and nanotechnology may be strange bedfellows; yet, as this paper highlights, peer interaction between a designer and a scientist is an effective method for helping scientists acquire visual design skills. We describe our findings from observing twelve sessions at the Design Help Desk, a tutoring center at the University of Washington. At each session, a scientist (who is expert in his own domain but a novice in design) consulted a designer (who is expert in design but a novice in science) in order to receive advice and guidance on how to improve a scientific visualization. At the Design Help Desk, this pairing consistently produced a momentary disequilibrium in the scientist's thought process: a disequilibrium that led to agency (where the scientist gained ownership of his/her own learning) and conceptual change in the scientist's understanding of visual design. Scientists who visited the Design Help Desk were satisfied with their experience, and their published work demonstrated an improved ability to visually communicate research findings—a skill critical to the advancement of science. To our knowledge, the Design Help Desk is a unique effort to educate scientists in visual design; we are not aware of any other design-advice/tutoring centers at public or private universities in the United States or abroad.

Introduction

Graduate students in science and engineering typically experience in-depth, rigorous training on how to conduct cutting-edge research. However, they receive far less education on how to effectively communicate this research—especially in the area of scientific visualization. Even though graduate students are expected to produce high-quality figures for scientific papers(1-3), posters and presentations, their studies rarely include coursework in visual design or visualization techniques. Instead, students learn in an ad-hoc fashion from peers and advisors, acquiring visual skills without a clear framework(4). This lack of knowledge in visual design is unfortunate, because visualization can be a powerful tool for scientific discovery, as well as a compelling vehicle for sharing information(5). By creating visual representations, scientists can explore speculative concepts, deconstruct complex relationships, and discover patterns and key features in their data. In addition, by externalizing their thinking in visualizations that can be shared with others, scientists facilitate communication with other scientists and the general public. There are numerous examples of scientific visualizations that have functioned as powerful and inspiring public revelations—ranging from Galileo's drawings of the Earth's moon (6), to Watson and Crick's double-helix model of the DNA molecule (7).

To address the gap in visual learning, a number of guides to designing effective visuals have been written for scientists and engineers (6, 8, 9). Many of these guides offer valuable frameworks for thinking about visual communication design and include useful comparisons of effective and ineffective scientific graphics. However, as many educators have discovered(10), simply creating the solution in a body of material and having it available will not necessarily cause the learner (in this case the scientist) to understand the content and the application of the processes prescribed therein.(11) Even though these texts are intended to be accessible to non-designers, they can be overwhelming to novices, who may have difficulty determining which lessons apply to their own work. In design, there are few black-and-white rules and rubrics that can be applied in a straightforward manner; most design decisions involve the subjective consideration of competing attributes.

At the University of Washington, we sought to make design knowledge more accessible to scientists and engineers by creating a visual design tutoring center called the Design Help Desk.(2) At the Design Help Desk, science and engineering graduate students can consult with a design graduate student or senior design undergraduate to receive visual advice and guidance on their figures, presentations, posters—any scientific visualization or graphic.

In operating the Design Help Desk, we became interested in understanding what kind of learning was taking place between scientists and designers. Were scientists gaining skills and knowledge, or were they simply following the specific directions of the design consultant?

If design-science consultations are indeed effective in helping scientists and engineers acquire visual design skills, such a model would be relatively simple to replicate at universities world-wide. Unlike efforts to incorporate visual design coursework into the curriculum of a STEM degree program, peer-tutoring sessions can be organized with modest effort and funding. Furthermore, peer tutoring is time-efficient (in comparison to enrolling in a semester-long visual design course) and provides scientists with targeted visual instruction on a critical issue at hand.

Materials and Methods

Subjects

We observed twelve subjects who voluntarily came to the Design Help Desk for advice on how to improve a visual figure that they had previously created in the course of their research. Participants learned about the Design Help Desk from a number of sources including: (i) advertisements placed on notice boards targeting University of Washington graduate students in science and engineering (see Appendix 1); (ii) classroom announcements by faculty and staff teaching in science and engineering; and (iii) word of mouth across campus as students discovered the availability of a tutoring center offering free help in designing visual figures.

Subjects included both graduate students and post-doctoral researchers studying science and engineering at the University of Washington (specific disciplines included the physical sciences, theoretical sciences, and nanoscience). There were an equal number of females to males, with ages ranging from mid-twenties through mid-fifties. The participants came from diverse backgrounds reflecting the general population of the University of Washington.

Subjects scheduled their 30-minute Design Help Desk appointment online. When subjects arrived at the Design Help Desk, they were reminded that their interaction could be part of a research study and were asked if they wanted to participate. Subjects were informed of their rights and told that if they preferred not to take part in the study that it would have no impact on whether or not the design consultant would help them (in fact, the designer never knew if a participant was in the study or not). When the subject agreed to be part of the study, they signed the research consent form. As it happened, all participants opted to be part of the study.

We sought and received Internal Review Board permission for this study. All necessary precautions were taken to preserve participant anonymity. Express written permission was sought and granted when pictorial images and verbal utterances of participants were used in associated publications and reports. Individuals in this manuscript have given written informed consent to publish their case details (as outlined in PLOS consent form).

Data Collection

We collected a mix of written and audio/video material. First, we asked each participant to complete a written demographic survey. Then, we recorded all sessions of the Design Help Desk with two video cameras. The camera setup (as shown in Figure 1) was always the same. One video camera captured the frontal expressions, body language and gestures of both participants as they sat at the same desk facing forward directly into the camera. The designer was always seated on the right, and scientist was always seated on the left. The second video camera was placed over the desk, suspended from the ceiling. This second camera captured what happened on the desktop, including the hand positions of both participants with respect to the desk and any paperwork on the desk. Both cameras were turned on before the session began and were not turned off until after the scientist left the room.

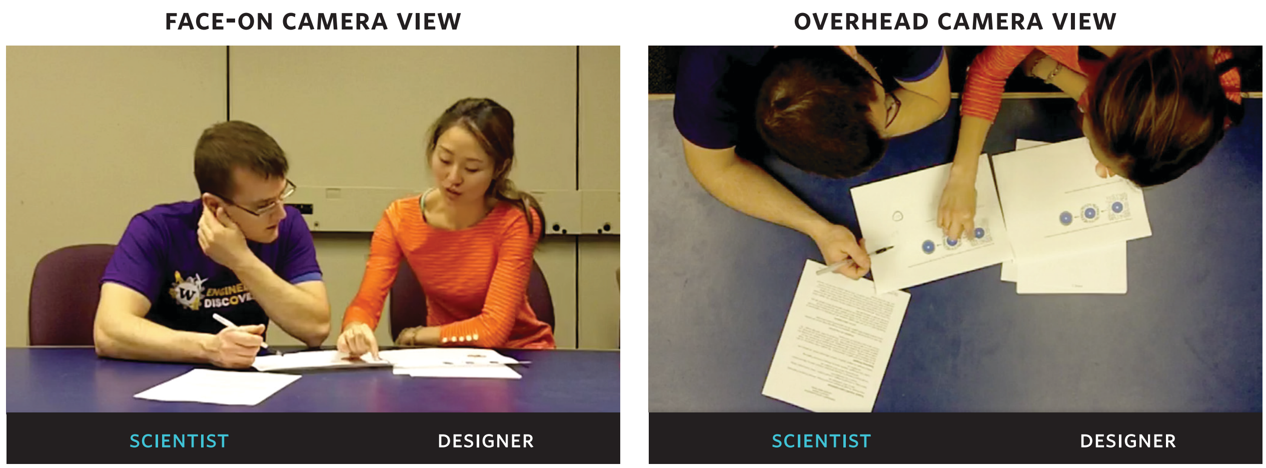

Figure 1: Camera setup at the Design Help Desk
At the Design Help Desk, the scientist was always seated on the left and the designer on the right.

The image on the left shows the "Face-On View," which captures the frontal expressions, gestures and body language of both participants.

The image on the right shows the "Overhead Desk View," which captures the gestures of both participants on the desktop, including interactions with the graphic printouts on the desk.

After each DHD session, the scientist received an email inviting them to complete a satisfaction survey regarding their experience. This survey (Appendix 2) also collected general demographic information, including academic background and previous experience/education in visual design.

To gauge the overall impact of the Design Help Desk, we later contacted participants after their session to ask if they made changes to their graphics following the consultation. We also asked if their graphic was subsequently published (for example, in paper, in a poster presentation, thesis, etc.) If we were unable to reach the participant, we conducted a literature search to determine if the graphic brought to the DHD had been published in a paper or other venue.

Data Analysis

We analyzed our video data using Interaction Analysis, as described by Jordan and Henderson.(12) Interaction analysis is an interdisciplinary method that uses empirical evidence to examine the interactions between human beings with each other, and with objects in their environment. Specifically, at the Design Help Desk, we examined both verbal and nonverbal interactions (as captured using the two-camera setup described above) to identify how issues relating to the scientist's graphics unfolded and were resolved at the Design Help Desk.

First, each videotaped Design Help Desk session was transcribed (our transcription convention is detailed in Appendix 3). Following the work of Goodwin (13) transcriptions included annotations for nonverbal communication such as changes in body position, gaze, and gesture.

Next, the videotapes for each session were played in front of a four-member working group. Each member of the group had been trained in interaction analysis methods and techniques. As the videos played, members marked categorical items of interest (e.g., conflict, agreement, collaboration, etc.) and halted playback for discussion of each marked incident. The individual stopping the video referenced specific verbal and/or non-verbal behavior to convince others of a particular claim or assertion about the apparent mental state or intention as evidenced in the interaction of the participants. Disagreement is common in this process, and in this case, was resolved through discussion and consensus.

Based on the collaborative viewing and discussion process described above, the working group identified a series of four phases that occur in a consistent sequence during Design Help Desk sessions (see Table 1, *Cognitive Interaction Coding*). Each phase includes two categories of activities/ interactions.

PHASE	ACTIVITY	DEFINITION	EXAMPLE	UTTERANCES (average)
ONE Introduction	**Explaining**	Describes the scientist's attempt to explain to the designer the graphical representation of the work.	SCIENTIST: I'm actually capturing the ... same stuff on both of the images, uhm ... that's ... kind of the point of this figure	115 = SCIENTIST 17 = DESIGNER
	Asking Permission	Describes the designer asking the scientist for permission to make changes to the work.	DESIGNER: Do you mind if I mark it up? (referring to the copy of the drawing)	22 37
TWO Knowledge Establishing	**Making Visible**	Describes the designer helping the scientist see his/her work from a new perspective.	DESIGNER: Explain maybe your goal in this ... are you wanting to make this look better? SCIENTIST: Yeah ... I want to make it, you know ... like ... when you look at it ... it's vivid	93 260
	Incisive Probing	Describes when the designer asks probing questions to further make visible what the scientist is trying to present.	DESIGNER: So your Figure 1 ... this is actually ... ahmm you can see that it is ... like this is ... ahmm it's not bird's eye view ... you're not looking at it straight on ... right?	257 540
THREE Conceptual Change	**Disequilibrium**	Describes a moment of internal disquiet when an unexpected notion causes mental perturbation.	DESIGNER: So ... all these ... these correspond ... SCIENTIST: Right DESIGNER: = ok ... ahmm ... I didn't get that initially ...	11 184
	Shift in Thinking	Describes the scientist adopting a novel idea as a result of the ongoing discussion related to the graphic.	SCIENTIST: = and it sort of ... dominates the image ... I don't think this is like ... obvious enough to be on the side ... or ... but ... if ...	94 278
FOUR Agency	**Agency**	Describes the scientist generating new ideas and contributing to the discussion.	SCIENTIST: Let's say there was two extra colors in here ... is that ... does that ... like ... add complexity where you don't really ... need it?	107 195
	Agreement	Describes a collaborative solution between both participants.	SCIENTIST: = one sided ... yeah? DESIGNER: = yeah! SCIENTIST: = ok? DESIGNER: Yeah, that will increase the effects	298 243

Table 1. Cognitive Interaction Coding
Analysis of twelve Design Help Desk sessions surfaced identifiable phases in the interactions between the designer and scientist.

Two main activities occur during each phase. The last column shows the average number of utterances during each of these phases. Blue denotes utterances from the scientist, while black is used for the designer.

The first and last phases are dominated by the scientist. The second and third phases have more utterances from the designer. Phases vary in length; Disequilibrium is relatively short, while the longest phase is Knowledge Establishing.

Following the efforts of the four-person working group, two members of the group then used the transcripts and accompanying video recordings to independently identify and code the agreed-upon stages and interactions in each of the twelve Design Help Desk sessions. Identification and selection of these interactional episodes correlated at ≥ .80, and interrater reliability among researchers was 0.95. Interrater Reliability was computed using Cronbach's A, which may be thought of as the average correlation among the research team.(14) Again, disagreements were resolved through discussion and consensus.

As shown in the last column of Table 1, we also measured the number and length of turn-taking utterances by each participant during each Design Help Desk session. We defined an utterance as any stretch of talk by one person, before and after which there is silence by that person. Using this definition, an utterance does not need to be grammatically correct. A participant who says "Well, I umm…" has spoken an utterance that is just as valid as a participant who says… "Well, I am not convinced." As noted by Wooffitt, all aspects of interaction—even fillers (such as umm, huh, ah. h… etc.), repeated phrases and idiosyncratic words (e.g., like, we..ll… etc.)—are valid utterances that may be significant in illuminating a speaker's mental state.(15)

In order to process the large quantity of discourse generated by twelve half-hour sessions, we used the visualization tool "Monologger" created by Tad Hirsch and Jonathan Cook at the University of Washington(16) to carry out moment-to-moment video analyses of the interaction between the scientist and the designer. Monologger captures and visualizes content logs of conversations as bar charts, therefore 'making visible' key aspects of participant interaction, such as the number of utterances, overall speaking time, turn-taking, and over-talk. These aspects of conversation have proved valuable in understanding how participants verbally (and non-verbally) exchange ideas in conversation under specific communication situations (17).

Results

Our video analysis shows that the Design Help Desk created a learning opportunity for scientists, with disequilibrium appearing to be the catalyst. According to Graesser(18), complex learning occurs when there is a discrepancy between an immediate situation and a person's prior knowledge, skills and strategies—in this case, the scientist's uncertainty regarding how to modify a visual to overcome deficits. In this scenario, the scientist experiences a gap in his/her knowledge—an impasse that causes confusion and frustration—what Piaget refers to as cognitive disequilibrium.(19) Piaget's theories have been verified in many research studies using behavioral and empirical testing in learning settings as diverse as neuroscience laboratories,(20) classrooms,(21) and workplaces.(22)

Disequilibrium appears to be key. It is related to categories of information (Piaget's schema), which reside in a person's executive function region (prefrontal cortex) and are central to consolidating learning through complex neural networks.(23) These networks become activated when an individual is prompted to re-evaluate prior knowledge and possibly assimilate it with new learning in the process of solving problems or creating new products.(24) This entails a transfer function(25, 26) that further promotes network activation with resulting neuroplasticity(27) to construct long-term memory(24, 28) and deep understanding.(29, 30) Willis asserts that without these kinds of opportunities for strengthening, any memories learned by traditional methods (e.g., rote) are simply pruned away from disuse.(23) Central to the learning that appears to be emergent in this interactive space is the notion of metacognition(31) that leads to agency(32) and personal fulfillment.(33)

To better understand the concept of disequilibrium, we review the phases of the Design Help Desk, as shown in Table 1, above. In Phase One—*Introduction*—the designer (as the more experienced participant) begins the Design Help Desk session (See Appendix 3, Consultant Script) by laying the groundwork for a proactive collaboration. However, the scientist dominates the conversation with roughly seven times more utterances than the designer (115 vs. 17), since it is his/her graphic that needs to be explained in context. We call this activity *Explaining*, since the scientist is describing and clarifying his graphic to the designer. During this time, the designer's responses are generally reinforcing statements that demonstrate empathy—often simply listening and, when appropriate, repeating back to the scientist what was just stated—a feature of pedagogy that establishes safety, agency, and collaboration.(34) For example:

Designer: So (0.2) before we begin (0.1) do you wanna just kinda give me an overview of what they're (0.2) they're [the figures] saying? ((laughs))
Scientist: Sure
Designer: What they're about?
Scientist: Sure (0.1) uhm (0.2) so (0.2) the (0.1) these are both locations on Mars (0.1) which is what I study ((laughs))
Designer: OK (0.2) good ((nodding))
Scientist: Uhm (0.2) and (hhh) so the reason that I'm doing the study that I'm (0.3) these figures are for (0.2) is because (0.2) uh (0.2) my advisor actually found (0.2) um (0.2) quartz at these locations (0.3) which is rare on Mars (0.3) so, (0.2) quartz is all over the Earth (0.2) but it's not on Mars anywhere except this location
Designer: Huh
Scientist: We're trying to figure out why (Hhh)

The *Introduction* phase generally ends when the designer asks if they can make changes to the work in question—when he or she *Asks Permission* to modify elements of the visual under discussion. For example, the designer may ask the scientist, "Do you mind if I mark it up?" (referring to the paper copy of the visual graphic they are jointly examining).

In Phase Two—*Knowledge Establishing*—both participants ease deeper into understanding the specifics of the graphic positioned on the desk between them—the object of joint visual attention. The designer asks *Incisive Probing* questions to try and *Make Visible* what the scientist is trying to present. For example, in this excerpt, the designer needs to understand the intention of the scientist in his rendition of double lines to show tectonic activity after earthquake events:

Scientist: There are two significant earthquake events that could potentially affect Puget Sound (0.4) one of them was (0.2) uh an earthquake on the (0.3) what's called the Seattle fault? and that was about (0.3) um (0.1) 1100 years ago=
Designer: =Is that indicated by these two lines?
Scientist: That is indicated by this (0.2) this gray line here=
Designer: =Yeah? that gray line?

By digging deeper with questions, the designer is encouraging the scientist to explain his reasons for creating the existing graphic—and setting the groundwork for possibly considering a new visual design concept. At the same time, the designer is also monitoring the potential for the scientist to become protective and/or reactive. The designer is skilled in interpreting reactive states and is prepared to advance or relax the approach (depending on perceived resistance) so that the session can proceed productively.

During this *Knowledge Establishing* phase, the scientist typically takes a 'follower' role, and the ratio of utterances reflects this, with the Designer speaking roughly twice as much as the Scientist (260 vs. 93). For example, in the following excerpt, the designer has the dominant speaking role:

Designer: I would say that (0.2) uhm (0.2) yeah (hhh) I (0.1) I (0.2) the- these definitely get lost
Scientist: Mmhmm
Designer: I mean I saw them up here in the blue, (0.2) and then green (0.2) I mean it also is the print-out (0.2) like you mentioned
Scientist: Mmhmm
Designer: Um (0.3) I think calling out stuff is fine (0.2) I mean,= (0.3) what I'm seeing the most (0.3) and (0.2) and where you're gonna see the most is the contrast
Scientist: Mmhmm
Designer: And so right now the contrast that I (0.3) it's all these lakes
Scientist: Mmhmm
Designer: And that's sort of (Hhh) giving me a really strong indication of land mass
Scientist: Mmhmm
Designer: But not necessar- (0.2) then I lose everything else
Scientist: Mmhmm

Phase Three—*Conceptual Change*—is dominated by two elements that are a critical turning point in the overall reaction of the scientist to the new information and to the realization that change was needed. The first is the moment of *Disequilibrium*—the Piagetian learning concept(35) that we discussed previously as a requirement for conceptual change.(36) The second is a *Shift in Thinking*—a moment of acceptance(37) when the scientist jumps back into the fray by generating new ideas(38) and contributing(32) elements that advance the project with the designer.

In all twelve sessions, the scientist demonstrated a visible and audible ‘Moment of Disequilibrium’ when they realized that the graphic might need a substantial alteration of a kind that they had not imagined before—perhaps even a major rethinking and/or restructuring of the design. As shown in Figure 2, the signatures of *Disequilibrium* in dialogue, hand position, and facial expressions were readily detectable and pronounced (39).

Figure 2. A closer look at the 'Moment of Disequilibrium'
Two instances of disequilibrium characterized by (a) who is speaking, (b) hand position, and (c) body language.

In (a) designer and scientist utterances/turn-taking are shown in a bar chart.
In (b) hand positions are mapped, with higher numbers indicating closer proximity to the desk and graphic.
Both (a) and (b) show the scientist withdrawing verbally and physically during disequilibrium.

In (c) both scientists exhibit the discomfort of disequilibrium (clasped hands and crossed arms are known signals of stress).

During the 'Moment of Disequilibrium' (and this was confirmed in every Design Help Desk session) the scientist expressed less words—typically, monosyllabic utterances—or lapsed into extended silence. As noted by Sacks et al, when silences occur at normal turn-taking junctures, this is usually a sign that the dyadic interaction has faltered.(40)

Our interpretation of *Disequilibrium* is further reinforced by the body language and gestures of scientists. Physically, the scientists withdrew their body and hands from the shared desk and paper. As noted by Graesser in his study of learner postures, the position of the body often changes when a learner experiences the confusion and frustration associated with cognitive disequilibrium.(19) Crossed arms are also suggestive of a subject's defensive stance. Pease describes this posture as a "barrier signal"—an unconscious attempt to block out a threat or undesirable circumstance (53). Similarly, a subject with clasped (or fidgety) hands—as occurred during *disequilibrium*—indicates discomfort, nervous tension, and/or fear (41). Similar learning signatures (accompanied by these kinds of moments of disquiet) were evident in a classic study involving incumbent engineers at an aerospace workplace when two methodologies were compared for active engagement, deep understanding and near and far transfer.(42)

We can also examine the dialogue that occurs during the moment of Disequilibrium:

Designer: Okay. So we've got (2.0) just look at (2.0) I'll do a draw…I'll leave this as like the original (Hhhh) um.. two ((inaudible)) things here
Scientist: Mmhmm
Designer: okay (Hhhh) um (2.0) 'cause what we would normally say (2.7) is like (2.0) you know (2.0) if this is sort of (Hhhh) I would say these floating numbers are sort of the issue that I see (Hhhh)
Scientist: Yeah I was trying to bring them outside of the box.. but for me it's still (hh) like.. I feel like each one should probably still be labeled
Designer: Yeah (2.3) um (2.3) and even.. you know (Hhh) you're giving it sort of an x and y
Scientist: Mmhmm

As evidenced in this excerpt, the moment of *Disequilibrium* appears when the designer states: "…these floating numbers are sort of the issue." The scientist first reacts with what could be construed as a defense, by saying "I was trying…" but trails off in his effort to argue this point.

As seen in Figure 3a, the body language and gestures at the 'Moment of Disequilibrium' are in direct contrast to the beginning (and indeed the end when generating new ideas and contributing solutions) of a typical session, when the scientist was close to the desk and used hand gestures to *Explain* his or her thinking as part of the *Introduction* phase.