Design Team Collaboration with a Complex Design Problem

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Abstract To what extent does collaboration impact complex ill-structured design? This research project focused on design meetings held during the first year of a 5-year, grant-supported effort to develop an innovative, 6-day course that integrates cutting-edge radiation physics and radiobiology content aimed at physicians and researchers working in the field of radiation oncology. The data set included over 568 pages, 208,842 words of written transcripts of a total of 15 two-hour meetings held over 6 months. Results indicate that designers use collaboration to manage constraints throughout the design process, inclusive leadership and decisive leadership are both used to keep the design process moving forward and designers use collaboration to build and rebuild prototypes in order to envision and refine solutions.

Keywords Design • Design thinking • Design constraints • Collaboration • Design prototypes • Ill-structured problems

Setting the Stage

The following is the story of Avery, an 8-year-old boy with cancer. This text represents a simplified example of the dense material the design team in this study was charged to work with; a small portion of content for one activity out of over 20 designed for the 6-day course. Reading this small excerpt will give you an opportunity to put yourself in the shoes of the design team, providing you a sense of the content and context of the design space. As you review the following paragraphs, my hope is you will think about the layers of content, the design of the "virtual hospital" activity, in which this content was embedded and the learners, M.D., Ph.D.'s in physics, biology, and radiology.

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Avery is an 8-year-old prepubescent Caucasian male who plays contact sports (pee-wee football). He begins complaining of a headache that gets worse over 1 week, accompanied by nausea/vomiting, and "clumsiness" (occasionally stumbling and losing balance). His mom takes him to the Emergency Room, suspecting that he may have a concussion resulting from football practice. On fundoscopic exam (visual examination of fundus of the eye) the emergency physician notes papilledema (swelling of the optic disks), indicative of increased intracranial pressure. A stat CT scan of the head reveals hydrocephalus (enlargement of the ventricles) in the fourth ventricle, and a contrast-enhancing midline mass, blocking cerebrospinal fluid (CSF) outflow. A malignant tumor is strongly suspected. An MRI of the brain better delineates a 4×4 cm mass. An MRI of the spine shows no other tumors in the central nervous system. He is then referred to a pediatric neurosurgeon. The pediatric neurosurgeon removes the mass the next day, and is confident that he did not leave any residual tumor. The tumor is sent to pathology. Because surgical estimates of the extent of resection may not be reliable, a postoperative MRI evaluation for residual disease is required within several days of the procedure. Three days postsurgery a postoperative MRI shows no residual enhancement in the fourth ventricle suspicious for residual tumor. An MRI of the spine and lumbar puncture (LP) is performed to test for metastasis and returns negative; therefore, his condition is identified as "standard risk." The pathologist's final diagnosis is medulloblastoma. Avery is then referred to a pediatric oncologist and radiation oncologist. The pediatric oncologist discusses standard of care treatment, which includes craniospinal radiation with concurrent chemotherapy (this allows for a lower radiation dose). Weekly vincristine chemotherapy is administered intravenously. Additional chemotherapy is given after radiation treatments are complete. The radiation oncologist discusses treatment. Radiation must be done to the whole brain and spine in order to sterilize any microscopic disease that's left behind in the brain or anywhere in the cerebral spinal fluid. Based on experience, if this treatment isn't done, this cancer is likely to return in the brain or spine.

Daily radiation (usual dose fractions of 180 cGy/day) is performed for approximately 6 weeks. The first half of treatment will be to the spine and whole brain. The second half will be a focused treatment to the area where the tumor was located (posterior fossa or tumor bed treatment). The short-term side effects for Avery can include cell counts going very low and a combination of radiation and vincristine can cause severe GI toxicity. Avery may face long-term complications including: radiation to growing bones can cause them to grow more slowly, head size and length of spine may be stunted, can affect brain development, mild learning or memory problems down the road, new skills may be more difficult to acquire, secondary malignancies: substantially increased lifetime risk of developing cancer in all areas of the body that received radiation.

Avery is treated by numerous radiotherapy professionals, most of whom operate in the silo of their profession and do not, generally as professions, collaborate with each other. Avery is receiving radiation, an area where research and education is also declining in the United States. What can be done to improve the chances of

Avery and others diagnosed with cancer to provide them with the best clinical care? How can we improve the clinical practice of radiotherapy for cancer?

Attempting to address this problem, The National Cancer Institute, a division of the National Institute of Health, awarded a 5-year research grant to an interdisciplinary team to design an innovative and advanced 6-day course that integrates cutting-edge radiation physics and radiobiology content aimed at physicians and researchers working in the field of radiation oncology. Requirements of the educational intervention include the demonstration of how to apply state-of-the-art knowledge in successfully delivering modern high-quality image-guided radiotherapy, planning relevant and productive research, and assuring the future availability of highly qualified teachers. The ultimate goal of this intervention is to improve cancer patient care and cure in the United States: no small task for an instructional design team.

The purpose of this study, part of a larger 5-year interdisciplinary grant-supported research study on the design and implementation of this medical program, was to study design team collaboration to see if and how it impacts design. The research question that guided this study was:

1. To what extent does collaboration impact a complex, ill-structured design problem?

Designing in Context

Design is described as a process of *meaning making*, engaged in creation from a holistic systems perspective (Nelson & Stolterman, 2012). In other words, things make sense when they are connected and interrelated or presented through relationships in context. Looking at design through this lens provides designers with a systems perspective. Nelson and Stolterman (2012) describe a process of creating a “design palette” (p. 89) in an attempt to predetermine the consequences of various choices in a particular situation. They suggest that designers and stakeholders must realize that not only are these choices inevitable as a part of achieving a design, they will be made whether or not the designers are aware that they are making them. Therefore, better choices are those made consciously, based on the designer’s judgment. To make the best design choices, the designer must view the design in the context of the whole system. “As every design is part of an environmental system, formed by a systemic context that carries systemic consequences with its implementation, the best design is one that is a whole-systems design” (Nelson & Stolterman, 2012, p. 91). Design is rooted in a context framed in time, place, and culture and designers must understand the context of the design situation as quickly and as well as possible.

Nelson and Stolterman (2012) state, “Design is about how to best integrate a particular design into a specific context and fit it into its environment” (p. 161). The context of this new design project included a national threat of a reduced knowledge base in providing modern high-quality image-guided radiotherapy, the lack of cross pollination in biologists and physicists who are planning and conducting relevant productive research, and the national reduction of highly qualified teachers in this field due to numerous researcher retirements. This problem escalated to a point where time became integral in the context of this design. The NIH demanded a complete program within 6 months. The design process had to be responsive to our context. Taking a holistic systems perspective provided us with the opportunity to look at the relationship of each part of this project. This perspective supported the impetus for the team, how we assembled it, how often we met and the goals that had to be accomplished by the end of each meeting.

Design Constraints

When a team begins to design, a first step is to gather information. It is during this time that initial constraints are often unearthed, and solution generation begins. Because the design problem and constraints are not clearly defined, the deeper the team delves into the design, constraints can provide an opportunity for the team to redefine the problem and the solution. Constraints can actually bring possibilities to innovate, refine, and improve the design (Cross, 2011). Constraints can force a design team to radically redesign initial ideas and are an important tool in supporting quality design. Because constraints are almost always synonymous with problem solving, researchers have attempted to design problem-solving models addressing the issue of constraints.

Models of design problem solving and dealing with constraints (Biskjaer & Halskov, 2014; Elster, 2000; Lawson, 2006; Stokes, 2006) are prolific, as researchers are attempting to support designers' need to solve problems while embracing constraints. Lawson (2006) categorizes constraints along three dimensions. The first dimension considers who generates the constraints; this could be the designer, the stakeholder, the end users, etc. His second dimension addresses constraints and context, i.e., are they internal to the design or are they within the context of the design problem. The final dimension focuses on the type of material for the design, the function, and practical application. Lawson's model illustrates the numerous constraints designers must not only deal with but embrace during design. He maintains that design problems are significantly composed of external constraints, over which the designer has little or no control.

Problem solving and constraints have been addressed while studying artists. For example, psychologist Patricia Stokes (2006) designed a problem-solving model addressing artistic creation. She suggests that artistic creation is about solving a creative problem, and following a constraint-based creative process model can intentionally generate the artist's ability to create real innovations. Jon Elster (2000), a social and political theorist, states that constraints serve art by focusing the artist's attention, maximizing the artist's goal to make aesthetic value under the given constraints.

Elster defines a constraint as one that is imposed by the material, requirements, and demands from the context including outside end users, stakeholders, budget, time, and artist self-imposed constraints which stem from the artist's own choices.

Biskjaer and Halskov (2014), researchers in interaction CAI, suggest that constraints can be a creative resource in interaction design and found that experienced practitioners view constraints as complex, at once restraining, impeding, enabling, and advancing a creative course such as a design process. They coined the term *skillfully balancing constraints* (p. 28), which they define as the ability to realize, define, and act upon circumstances and conditions in a creative process. They argue that these constraints share (at least) two key characteristics: they are grounded in *radical decision-making* by going against easy and common creative choices as solution alternatives, and they *accelerate the design process* by pushing it forward in the form of an unexpected leap. They maintain that constraints are always a part of a creative activity regardless of their origin whether they are external requirements of the design, design materials, or chosen by the designer himself. There are also various strategies for the designer to approach these constraints. The early-identified constraints of the brand new design project described here included internal and external constraints. Heavy time constraints on the design team combined with the looming final delivery date; a complexity of the overall task and final product, dense content, and numerous stakeholders all impeded and improved the design.

Design Collaboration

Collaboration while designing is not a new concept although instructional design activities are often done individually. Some question whether this is the best way to design (Brown, 2009) and if a "radical form of collaboration where designers migrate toward ever-deeper collaboration not just among members of a design team but between the team and the audience it is trying to reach" is needed (p. 58). Brown states that we must look at design as an opportunity to work *with* the stakeholders and end users, not *for* them. Business and industry, he contends, should think about how more time could be spent doing collaborative, procreative work in face-to-face time. Brown argues that this will produce a solid outcome because face-to-face time nurtures relationships and inspires teams and is one of the most precious resources an organization possesses. In terms of design, Brown states that time collaborating in teams should be as productive and creative as possible where each person builds on the ideas of others. When design is happening in real time and among people who know and trust one another, he believes this makes design easier (Brown, 2009).

Design collaboration, however, is not always an easy or intuitive activity. Studying designing in teams Brereton, Cannon, Mabogunje, and Leifer (1996) noted that each individual designer should possess behaviors of collaboration that include expressing ideas, listening, and negotiating. A design team's process is quite complex and controlled, with numerous levels of activity occurring at the same time even if it appears to be free flowing to those outside of the team (Cross, 2011). Brereton et al. (1996) discovered that designers working in collaborative teams are constantly engaged in numerous activities at different levels and continuously look at alternatives while reflecting, monitoring, and modifying their process and course of action. Solutions are created based on the requirements and a constant review of various solution alternatives. The design team on this project attended mandatory 2-h meetings in one room, around a circular table where an initial idea was introduced to begin the creative design process. There were no breaks, cell phones were turned off, and the only goal was to design, by identifying constraints, creating ideas, and building on them. Each team member chosen because of their developed professional identity (Tracey & Hutchinson, 2013) possessed the ability and desire to create an innovative design, and also had a stake in the realization of the final product.

Designer Judgment and Identity

Fundamental to the design thinking approach, as outlined by Boling (2008), Cross (2011), Lawson (2006), and Nelson and Stolterman (2012) among others, is the idea that designers are the dynamic drivers of the design process who use their knowledge, experience, and intuition to navigate the design space and recursively refine both problem and solution until an innovative outcome is reached. Design relies on designers' judgment, or the ability to balance elements of the design problem against their own storehouse of design knowledge, which is highly personal and can't be separated from the knower, in order to reach decisions (Nelson & Stolterman, 2012). Design knowledge emerges from the accumulated episodes in an individual's history of design choices and consequences, both directly experienced and observed; these episodes have been conceptualized as design precedents (Tracey & Boling, 2013). Reflective thinking, another concept foundational to design thinking (Cross, 2011; Schon, 1987), provides the designer with a pathway to consider and reconsider design precedents in the face of complex and novel design problems (Tracey & Baaki, 2014), leveraging them in service of design judgment, decisions, and action (Tracey, Hutchinson, & Gryzbyk, 2014).

Design thinking highlights the central role that designers play in developing novel, functional solutions to ill-defined problems (Siegel & Stolterman, 2008). Designers recognize that problems and solutions are entwined concepts, but that the relationship between the two is complex, evolving, and often oblique. And as designers move through the design space between problem and solution, they must rely on their design intelligence and intuition or their designer identity. Within instructional design, professional identity development is intimately linked to the concept of design precedents (Tracey & Hutchinson, 2013). Designers on this project were chosen not because of the number of years of experience (although it accumulated to over 60 years of design experience and 50 years of biology and physics experience), but because they were grounded in their professional identity (Tracey &

Hutchinson, 2013) and believed in the skills of their design judgment. This was a concentrated, constantly changing design, and each member possessed the ability to immerse him or herself in the project and bring relentless energy to the team.

The Design Team

Design teams are made up of individual designers, each bringing their own knowledge, experience, and intuition to navigate the design space and recursively refine both problem and solution until an innovative outcome is reached (Tracey et al., 2014). Assembling the appropriate team was critical to the success of this project. Nelson and Stolterman (2012) state that "an appreciative judgment, appreciating what is important to consider and what is not; whose interests need to be taken into account and whose do not; and what level of complexity must be maintained as a substitute for never-ending comprehensiveness. It is within this context, and against this environment, that the design process unfolds," (p. 115). The two grant Co-PI's, me as the researcher in Instructional Design (ID), and the other a researcher in Biology were key leaders on the team, each bringing their expertise in choosing the remainder of the team. Two additional Co-Investigators on the grant, a researcher in ID specifically in assessment and evaluation and a researcher in Physics were also critical to the team. These four members, in part due to their roles on the funded grant, brought biology and physics content expertise in addition to the needed instructional design expertise.

The two designers interviewed and hired four additional designers to work on the team. Each designer had worked with the designer Co-PI and/or were current graduate students in the Instructional Technology program at the host university. Knowing the depth of the content, the compressed design and development time and the overall complexity of the design project, we hired designers who had a minimum of 6 years experience specifically with complex projects. These, however, were initial selection criteria. A conscious effort was made to select designers who possessed the ability to be flexible, reflective, and self-confident in their design judgment and had the ability to have their ideas analyzed, changed, and built upon. Although this may appear to be logical, realizing this project was too complex for individual design efforts, we had to ensure that the designers were able to join and help cultivate a quickly functioning team. The importance of this cannot be underestimated and this conscious decision played a significant role in the success of the design space and the end product. The biologist and the physicist served as the content subject matter experts, but, more importantly, provided access to additional biology and physics researchers and physicians and clinicians to support our design efforts along with a window into the end users. As the design team proposed ideas, these SMEs provided instant critical feedback on the viability of the design. Figure 1 illustrates the project team with a brief description of their roles. Additional team members included consultants in graphic design, desktop publishing, computer programming, and web site development. We brought these individuals in on an as-needed basis and worked with the designers to develop products.

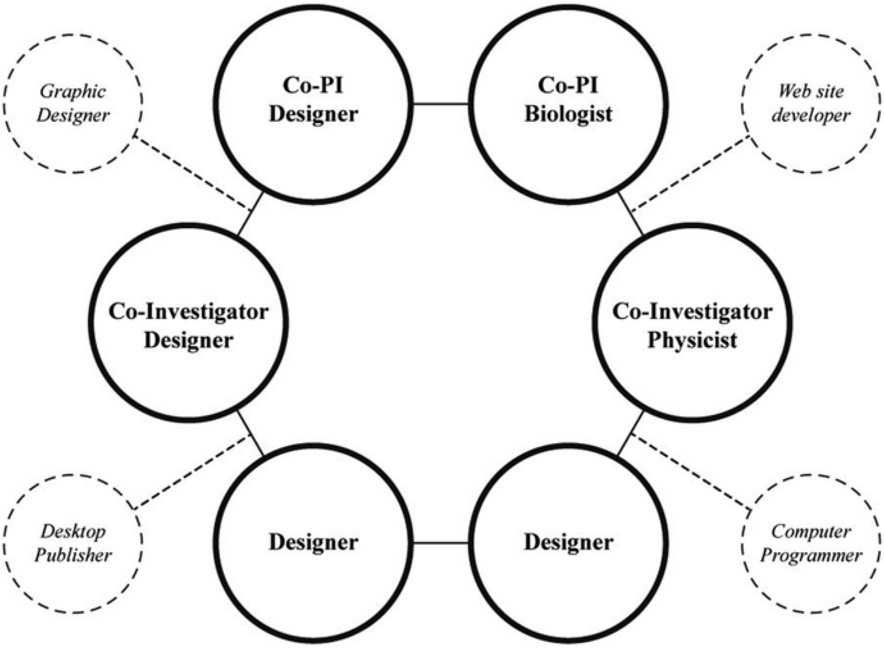

Fig. 1 The design team

Methodology

This research followed a protocol analysis methodology. Described as the ideal method to "bring out into the open the somewhat mysterious cognitive abilities of designers" (Cross, Christiaans, & Dorst, 1996, p. 1), this method follows a research-through-design approach (Basballe & Halskov, 2012; Dalsgaard, 2010; Halskov, 2011). Using protocol analysis, which relies on the designers' verbal accounts of their activities, we documented the verbal exchanges of members of the design team engaged in the shared task of designing the 6-day medical course. Cross et al. (1996) argue that protocol analysis appears to provide data revealing the cognitive activities assumed by the design team members.

We focused on design meetings held to develop our innovative, 6-day course, integrating cutting-edge radiation physics and radiobiology content aimed at physicians and researchers working in the field of radiation oncology. The data set included written transcripts of a total of 15 meetings held over 6 months. Participants, described above, included the two Co-PIs, two co-investigators, four additional instructional designers, and pertinent outside consultants such as a web developer, desktop publisher, and a graphic designer. The number of participants at a given meeting ranged by meeting (and within meeting, as consultants would typically only attend for portions of a meeting) from a high of seven to a low of four, with an average meeting duration of 2 h. Transcripts of audiotaped meetings, 568 pages

(208,842 words of text), were prepared from audiotapes by a graduate research assistant familiar with the grant, who also attended some of the initial meetings to garner an understanding of the project scope. Each designer had advanced degrees in Instructional Design and Technology, three held master's degrees, one was a doctoral candidate and two held doctoral degrees. Each designer had no less than 6 years design experience, with the most senior designer working in the field for 27 years. The designers worked in numerous areas of design before joining this team, although none had professional experience in designing in the medical field.

Data Analysis

For the data analysis, two doctoral students in instructional technology (who were not involved with the grant) served as the initial reviewers, while the primary investigator on the grant, and I as a professor of instructional design, served as the final reviewer. During initial data analysis, the reviewers read through the transcripts to understand the events and trajectory of the design process, taking notes and rereading as necessary to develop a deep knowledge of the content and to identify preliminary themes related to collaboration. The goal of this reiterative process was to gain a picture of the issues and actions that seemed most important to understanding how collaboration shaped the design process and influenced the design solution. Once the reviewers completed this process, they formalized their findings by identifying three themes that most clearly demonstrated how collaboration contributed to a refined ID product and supporting their conclusions by referencing specific events from the design meeting transcripts that illustrated these themes. At all times during this initial data analysis period, the reviewers worked independently to develop their own sets of themes and corresponding notes, with no knowledge of the other's findings.

Once the initial reviewers had completed their inductive content analysis, their findings were submitted to the third reviewer, who reviewed their findings for validity, integrated identified themes where possible, and made final decisions on the identification of the final themes based on the evidence presented by the two initial reviewers as well as her own experience on the design team. As needed, the third reviewer consulted with the two initial reviewers to gain clarity on their findings, gather suggestions for integration, and gain consensus for the final results of the data analysis.

The Results

Design requirements included designing a 6-day course integrating cutting-edge radiation physics and radiobiology course aimed at physicians and researchers working in the field of radiation oncology. Three themes emerged under the research question, to what extent does collaboration impact a complex ill-structured design problem?

Designers use collaboration to manage constraints throughout the design process. The constraints presented in this study support research conducted by Cross (2011) in that they initiated innovation, refinement, and improvement in the design. Collaboration supported us in identifying the constraints, elaborating on those constraints, revising the constraints when needed, and ultimately recasting the constraints as opportunities. Design meetings provided the opportunity for the team to identify and/or reiterate individually or as a group the immediate constraints depending on where we were in the design space. The keynote presenters, experts in physics and biology ($N=24$), the keepers of this inordinately difficult content were a monumental constraint, identified in the data analysis as the second most challenging constraint behind time. Efforts to contact these chosen keynote presenters were unsuccessful and the learning curve of what they do and how we needed to design for this content is almost insurmountable. Discussions on how to manage this constraint via technology by attempting to email questions to garner information ensued, although unsuccessful. Ultimately, several collaborative discussions describing each designer's experiences attempting to work with the keynote presenters resulted in the design of a consistent process incorporating numerous audiotaped meetings, visits to their workplace if possible, and/or scheduled conference calls.

As indicated, time was the number one constraint and, although the data indicates it could actually be its own theme, it is included as one of the constraints for this chapter. Time constraints included the design schedule, the keynote presenter's schedule and availability, and how future iterations of the design could be impacted by current design decisions due to the scarcity of time this first year. The data indicated that the shortness of time forced the design team to brainstorm and innovate in a productive manner. Design meetings were productive from beginning to end, as time was not a luxury the team had to complete this project. During design decisions, the team indicated which design ideas had to wait to be included in future design iterations, but smaller scale options were often created for this first year. For example, an idea surfaced to have participant teams develop a clinical trial. This activity required in-depth research and design, and first year time constraints prevented it from coming to fruition. As an alternative, the team researched existing clinical trials and designed questions and concerns for the participant teams to debate. This activity was well received and is the foundation for the design of the clinical trial activity planned for year 2.

One unknown was the physical layout possibilities of the conference room housing the 6-day course. This challenged the design team while we attempted to design participant activities to meet one of the overarching course goals, to provide instructional activities focusing on interdisciplinary participant collaboration. One team member resolved this constraint by uncovering pictures of the room illustrating various meetings and trainings on the Internet and sent them to the rest of the team. After viewing the online photos, the team discussed the physical room constraints and made decisions on room set up to accommodate the participant group numbers: where the projector needed to be for keynote presentation slides to allow participants the optimum viewing opportunity and how the white board activities would work. In this instance, the physical constraints were better-understood and overcome with visual reference and discussion.

The 6-day course opened to biologists, physicists, and clinicians provided the opportunity for the design team to identify, collaborate, and attempt to resolve the participant knowledge constraint. After meeting with a keynote presenter, one designer confirmed that biologists and physicists don't communicate with each other and are unfamiliar with the literature outside of their professional area. We realized that we were dealing with two totally different languages along with a lack of current professional practice integration. Discussion of this constraint resulted in agreement that this was a complex issue and would substantially affect the design. This constraint was preliminarily resolved by the grant leaders, the Co-PI designer who served as the team leader working with the Co-PI biologist and the Co-Investigator physicist, to assist the design team with the content. In this instance, the leaders of the grant had to resolve the issue by coming to consensus on the content that best educated both professional groups. Most of the identified constraints were elaborated on, revised, and resolved in the team: however, leadership was needed at times to make decisions and move the design forward.

Inclusive leadership and decisive leadership are both used to keep the design process moving forward. Design team leaders need numerous skills, but the most essential character trait is that they are designers (Nelson & Stolterman, 2012). When defining leaders, we tend to think of someone appointed to a specific position or possessing a particular role. In a collaborative design situation, leaders are those who propose the vision of the design along with an enthusiastic judgment of what is possible.

Roles were identified, naturally emerging, and at times changing in this collaborative design team. The team was well balanced in their roles and managed their negotiation well (Cross, 2011). The Co-PI designer served as the team leader and facilitator during design meetings. She used facilitation promoting inclusive leadership at the beginning of each design session through the initial idea generation process. Statements such as *What do you all think*? and *I am wondering* prompted the team to contribute to and refine ideas. While inclusive leadership seemed to be linked with eliciting ideas, decisive leadership was more associated with choosing discussion topics and making decisions. The Co-PI designer used her position as leader to open one meeting stating, "I want us to walk away today with a picture of how we see each day will look, and what we need to ask the keynote presenters to do, and how we are going to start creating those activities." This sets the agenda for the design meeting, and also linked to the third theme, using collaboration to build and rebuild prototyping (discussed below). Cross (2011) states that a design teams' need for explicit planning of activities is evident in their collaborative work. This was demonstrated repeatedly during team meeting initiation. Both inclusive and decisive leadership were used to set the agenda either in the beginning of the meeting or at the end of the previous meeting, with the team coming to consensus.

Ideas emerging from agenda items were further refined via a facilitated discussion: "Let's talk about some of their (keynote presenters) feedback so we all know that we are incorporating it into our design." Inclusive leadership in the form of facilitation is demonstrated on how the Co-PI designer directed the flow of the discussion: "We have to flush this out. Okay, now we're starting to get down to some specifics," followed by discussion which eventually led to the identification of additional constraints (theme 1, discussed above). After these constraints were discussed and resolved, the Co-PI designer kept the conversation moving forward: "Alright now, what else, what are the other issues?"

Questions, including probing questions like, "Tell me more, how would that look?" and clarifying questions, "I thought there were going to be two videos… but what makes sense," and refining questions, "What about if we come up with the guided questions and have the keynote presenters edit them?" are examples of inclusive leadership that fostered collaboration while continuing to move the design forward. While inclusive leadership led to discussion to gain consensus, there were times when decisive leadership was enforced, including once the need to reassert the role of the designers with the keynote presenters in the process emerged: "We have to make some decisions and make mistakes on our own," and "That's a design decision we are going to have to make." Decisive leadership in these moments was necessary to preserve deadlines and manage communication with the keynote presenters. Decisive leadership in these instances also provided the opportunity for the designers to reestablish their roles as designers rebalancing the entire research team.

Designers use collaboration to build and rebuild prototypes in order to envision and refine solutions. Visual lists, phrases, and words on large posted flip chart paper used during design team meetings stimulated idea generation and evolution (Fig. 2). Decisions were summarized and reinforced while new ideas were simultaneously generated. These visuals were combined with verbal prototypes, design ideas articulated verbally, encouraging rapid dialogue/questioning to build on the initial idea and create instructional strategies. Accuracy/understanding of the verbal prototypes was an issue that kept coming up (via designer questions or misconceptions of what the prototype consisted of, particularly related to the schedule and the morning activities), but this appeared to be an opportunity to gain consensus/clarity *or* to further refine the prototype based on the verbally described confusion. A team member asked a question "So wait a minute, let me just back up and ask a question. This is just the morning segment? We have 3½ h of the morning. Is that what you said? So basically you get two themes a day…" This prompted a discussion on how the day's schedule would be framed. Verbal prototyping was used to better understand the problem (How many lectures will we have?) and tentative solution (how time will be allotted). "What I'm hearing is that where we give an hour for a talk, we have two sections of question and answering, and maybe what are we thinking. Forty-five minutes for those two pieces?" This example of verbal prototyping of the day's schedule (rebuild) resulted in clarifying and refining the schedule.

These design ideas articulated verbally, or through verbal prototyping, and sketching drove the design. The introduction of ideas, "OK let me, before I show you, let me draw it. Is that ok? Let me draw what I was thinking and uhh…" The designer used a graphic as the impetus for a discussion of the pathways to treatment/virtual hospital activity, while other designers clarified via questions and added their own ideas. Prototyping the design led to design refinement: "Ok, so we have to now spend the rest of our time working on the workshop. They have gone through an opening activity and two lectures. They've gone through a patient, two guided questions with

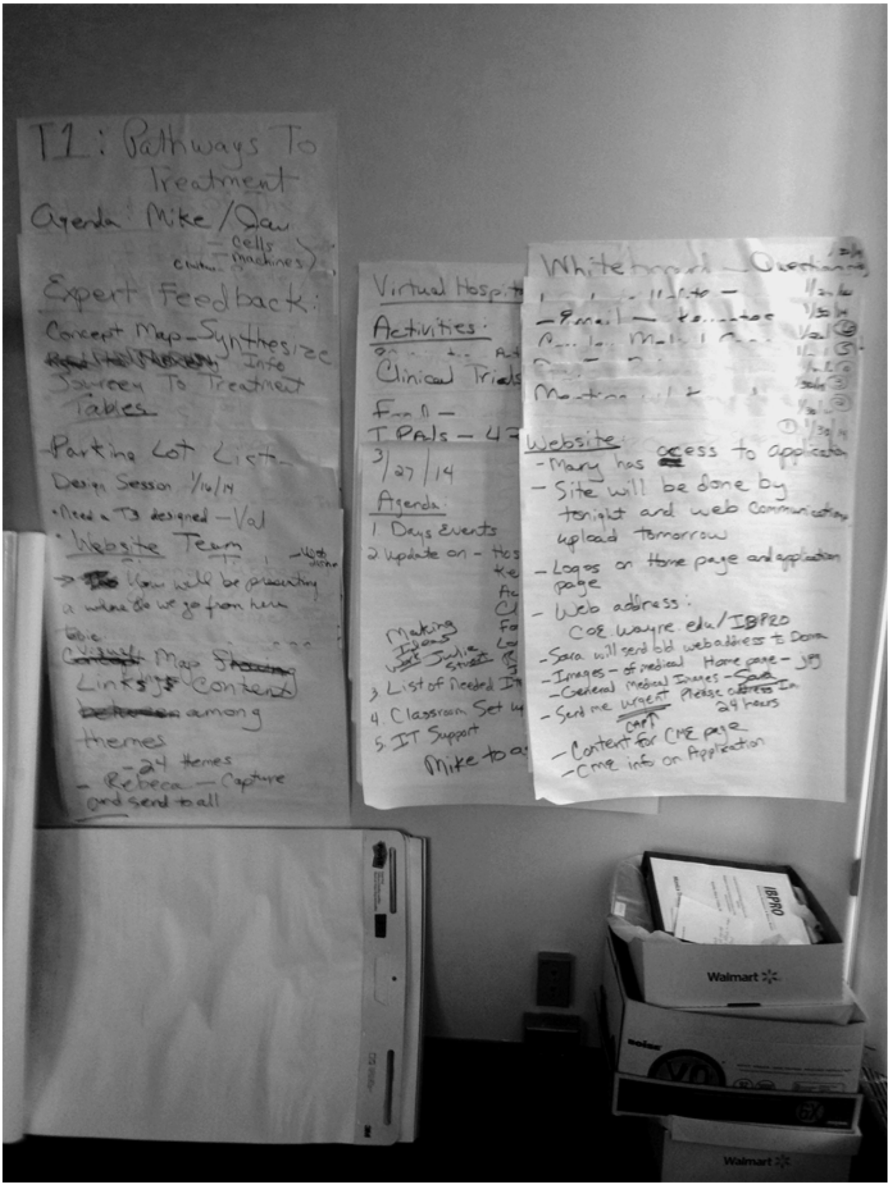

Fig. 2 Prototype example

a patient. They learned two themes, am I right?" The verbal description of the morning activity led to discussion of terminology to modify the design idea. Tentative ideas were introduced which also led to verbal prototyping, "We may have talked about this already, but Dr. D. asked if there was an opportunity for something like office hours?" Discussion followed where the team verbally constructed how the office hours might be implemented (timing, sign up) with multiple inputs to refine the idea. Office hours were ultimately implemented as a design strategy.

Because design meetings included the Co-PI biologist and Co-Investigator physicist, we had the opportunity for multiple revisits of the prototypes to ensure all group members understood and endorsed it. When the initial design idea of complex medical cases introducing each morning's themes was presented, it was purposefully revisited at a subsequent meeting with the Co-PI biologist. "Ok so let's blow this out. To create one prototype so that then we know what we're dealing with and we know all of the components that need to be in it. We have to start with one. Can we start with this one [points to one from a list on the wall]? And if we do, who do we need to work on it?" Discussion of the complex medical case ensued, including defining what it means, what doesn't need to be included, what should be included, and its overall goal for each morning. The Co-PI designer refocused the complex question that introduced the case to the participants and used input from the three other designers to clarify the question for the Co-PI biologist, but he came back with a need to clarify three more times. In each instance the prototype was repeated and refined until consensus was gained.

One design meeting with the Co-PI biologist and Co-Investigator physicist resulted in prototyping of what the main focus of keynote presenter lectures should include. The physicist began, "I was hoping that we will brainstorm some ideas, too, like you guys have some ideas about how to reach all three audiences, or all three participant types with one lecture." The biologist and physicist dominated discussion at this point because both were the content experts. Three designers, however, contributed to the discussion and ultimately a prototype of what keynote presenters should be doing was focused from broadly reaching three audiences to having keynote presenters specifically focusing on how to do research, how to get from where we are to where we want to be, which was also determined to be integrated into activities.

Collaboration with prototyping resolved questions regarding the feasibility of existing ideas in the design. Initial design connected the morning and afternoon daily themes through a patient activity. The designer who led the design of this activity described her idea; "Yeah, sorry. The opening activity after lunch, *the results are in role play consultation*. This is how it looks. Additional tests results are now in on Avery that deal specifically with or that have to do with imaging." The designer reviewed the current prototype of the afternoon activity. The CO-PI biologist asked clarifying questions that the designers answered, then the CO-investigator physicist pointed out that, based on this version, the keynote presenters would be interacting with someone on video (a constraint), which triggered an idea for removing the video and instead use another medium such as email, etc. The team came to consensus on the removal of the video consultation and used another form of communication. Through prototyping, a constraint was identified, resolved with an opportunity; the group came to consensus and the design moved forward.

Collaboration to build prototypes was used to gain consensus (inclusive leadership, theme two), but at certain times a decision to go with a particular prototype (or revisions to an existing prototype) was made by the research team leadership (Co-PIs) without polling the team. This action of decisive leadership (theme two) usually resulted from time constraints (theme one).

Discussion

Writing about collaboration and design, Lawson and Dorst (2009) suggest, “design on a substantial scale is essentially a collaborative effort… the ideas in a design firm often emerge from a collaborative creative process, rather than from a single contribution” (p. 187). There are numerous insights we now have because of this research project. We observed immediately that any known form of linear design process was not going to work on this design. Collaboration occurred at several levels that rarely happen in a design situation. If the careful selection of each team member did not happen, the collaboration would not have emerged in the manner in which it did and the final design product would not have been successful as it was. The Co-PI biologist’s and Co-PI physicist’s initial and ongoing presence on the design team was critical to the success of the final product. Having each of these content experts in all of the design meetings assisted the instructional designers in managing the complex content. Not only did we produce a viable product in spite of this complex problem and the numerous ongoing constraints, the final product was enhanced due to the ongoing intense collaboration of the design team. Rarely was a task assigned to one person and one person was never solely responsible for a design decision. Collaboration in this case shaped the design process and products through idea generation, discussion, refining, and consensus. Collaborative discussions on how to handle constraints resulted in solutions that would not have been possible with a single designer.

The final design product was not a random solution. Distinct design decisions were made largely because of the inclusive and decisive leadership used to keep the process moving forward. The Co-PI designer led the team consistently, opening meetings with probing questions leading to idea generation and discussion, traits of an inclusive leader, while at the same time being cognizant of time and the need to keep the design process moving forward. Decisive leadership appeared to be necessary to keep the deadlines, manage communication with keynote presenters, and reassert the designers’ roles in the process as needed. Upon reflection of the end product, it is difficult to remember which team member initiated which design idea due to the rapid collective discussions and building and rebuilding of the prototypes creating and refining the design.

This research indicates that collaboration was a necessary skill in design when working with an ill-structured problem, while illustrating how designers need to be able to collaborate not only with fellow designers but also with others outside of our field (Buchanan et al., 2013). The research team on this project was comprised of disciplined, effective experts in their professions. This seasoned group of people created this innovative end product. This is an example of designing much in the manner other design fields. We maintain that this design was successful because of the expertise of the players, the decision to design in context, the ability for all to manage and embrace constraints, the designer’s judgment and identity, and the conscious selection of the team. We anticipate that the results of this research will not only assist us in improving our design over the next 4 years of this project but may also aid other design teams working on complex ill-structured design problems.

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