# Collaborative Storyboarding: Artifact-Driven Construction of Shared Understanding

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## ABSTRACT

Collaborative storyboarding, with a focus on aggregating designers' expertise in the storyboarding process, offers the opportunity for a group of designers to make progress toward creating a visual narrative for a new interface or technology, but it requires the designers to work together to explore ideas, differentiate between options, and construct a common solution. Important in collaborative storyboarding is the shared understanding that emerges among the designers and the obstacles they face in establishing that understanding. This paper defines a model for collaborative storyboarding, presents a study that explores group interactions in collaborative storyboarding, and analyzes the interactions using the distributed cognition and common ground theories. Our findings demonstrate that joint interaction and enthusiastic efforts within each phase lead to active information exchanges and shared understanding among the members of the group.

## Author Keywords

storyboarding, collaboration

## ACM Classification Keywords

H5.3 Group and Organization Interfaces: Evaluation/Methodology

## INTRODUCTION

A *storyboard* typically consists of multiple panels (numbering from three or four to dozens or hundreds) that describe actors and a series of actions that are most important to a story. Storyboarding first rose to prominence in the movie and advertising industry, used to highlight the key aspects of a cartoon, film, or commercial in the early stages of development [9,13]. In the field of human-computer interaction (HCI), storyboarding as a design technique describes interaction through a series of graphical descriptions and textual narrative. It has been adopted as a tool for illustrating key sequences of user-system interaction, often through sketches, composite pictures, or modifications of prior storyboarding panels [5].

Storyboarding literature has focused on the technique in a highly centralized manner, without considering roles that multiple designers can have in the process. Increasingly, design projects are faced with situations where team members with different backgrounds and skills bring disparate ideas and interpretations to a design session, necessitating renewed investigation of storyboarding. This paper explores *collaborative storyboarding*, an approach to storyboarding that focuses on combining differing approaches in the storyboarding process, where the content, narrative, and pictures are assembled through interactions among designers. While certainly there has been collaboration on storyboards in the past, this paper seeks to explore questions about the nature of the collaboration—stages unique to collaborative storyboarding, points of success and conflict among designers, and occurrences for which intervention by a moderator or tool potentially could be of benefit.

As with other collaborative activities, collaborative storyboarding focuses not only on creation of a design, but also in establishing a shared understanding among the group members. We envision that the more interesting incidents in collaborative storyboarding will emerge from designer interactions, in which designers combine their interpretations of artifacts toward a broader shared understanding of the design space. As such, benefits from collaborative storyboarding stem from artifact-based reasoning—how they can be utilized and integrated.

This paper presents a study in which seven collaborative storyboarding sessions, analyzed using the theories of distributed cognition (DCog) and common ground, yield insights on a model of collaborative storyboarding with three phases: exploration, differentiation, and construction. Our DCog analysis demonstrated how participants relied on an artifact representation to externalize information as they progressed through the phases. The common ground analysis articulated the importance of gestures, utterances, and artifact placements in key activities carried out throughout the sessions. We do not primarily consider what

was designed, instead focusing on the collaborative nature of the activity. Our findings demonstrate that joint interaction and enthusiastic efforts within each phase lead to active information exchanges and shared understanding among the members of the group.

## RELATED WORK

Storyboards have been used to help understand the flow of the story, to eliminate costly elements of a design, and even to decide how to pitch ideas to others [5,22]. Storyboarding is the process of describing a user's interaction with the system over time through a series of graphical depictions and units of textual narrative. Similar to other fields, in HCI storyboards are used to identify opportunities and costs in the creation of a new device or interface. Key aspects of a storyboard are the portrayal of time, the inclusion of people and emotions, the inclusion of text, and the level of detail [27]. Tools that support the creation of storyboards have also been created [3,16,17], but they too focus on individuals using them to create the storyboards for systems being designed.

The efforts in this paper focus on collaborative storyboarding in a shared workspace, an environment in which visual information about relevant shared objects is provided [30]. Shared workspaces facilitate modification of shared objects and observation of the effects of the modifications made by others [30]. Thus, the actions performed on objects are intended to be transparent and are indeed important aspects in a shared workspace investigation [30]. Investigations of shared workspaces for design session have also been carried out and lead to frameworks of collaboration [10,25,18]. Tang and Liefer articulate the role of storing information, sharing ideas, and engaging attention with respect to the use of gestures [25]. Gutwin and Greenberg's framework outlines the mechanisms and knowledge related to maintaining awareness [10]. Minneman's work serves to emphasize that design sessions are not just a set of technical processes, but that collaborative factors are intertwined [18].

Shared workspaces can be analyzed with respect to many models. Whittaker mentions the use of common ground and DCog theory for shared workspace analysis [30]. Common ground is a linguistic model that describes the process by which collaborators achieve shared understanding [6]. Clark's model identifies the three-stage process of grounding conversations in which participants achieve incremental understanding that builds upon previous shared knowledge. This model has been used in many past endeavors to help explain communicative process and guide design requirements [15,26,28,29]. Clark and others have also built upon this model in an effort to explain the role of non-verbal or gestural communication in the process of achieving common ground [8,7].

DCog is a model that goes beyond the individual's mind [14] to understand the way in which people and environmental artifacts can support problem-solving through the creation, transformation, and propagation of representational states [20]. The unit of analysis is typically a functional system which can be formed of individuals and artifacts [20]. Thus, information can be seen as transitioning from internal memories to external representations of knowledge created within the environment as a result of the offloading of memory [14,20]. When applied, the theory aims to make a contribution to system design—particularly those meant for collaborative work—by making the relation between individuals and artifacts more explicit [11,21]. It has been applied successfully in various collaboration-related research efforts [1,12].

## COLLABORATIVE STORYBOARDING

Certainly, collaborative storyboarding is not a new phenomenon; the need to incorporate diverse perspectives in the design process has long been identified. However, we are yet to find a formal study of the nature of the collaboration that occurs in collaborative storyboarding sessions—a motivating force behind our inquiry.

A collaborative storyboarding session typically involves the creation of a traditional storyboard in a group setting starting from sketches. Our unique conception of collaborative storyboarding focuses on the use of artifact templates—such as ideas from collaborators on note cards, pictures, patterns, or interface components from a repository [2,5,19,24]—to jumpstart and inspire the design process and eventually be utilized in the storyboard. Although the end product carries similar narrative qualities as a traditional storyboard, we believe the templates result in a distinct presentation format. We also believe this approach will duplicate and extend some key advantages of more traditional storyboarding, including the gain of diverse perspectives, promotion of creative ideation, and discussion of user-focused design trade-offs. While this process might decrease the amount of time spent on creating new material for the storyboard, this type of work emphasizes the importance of the time spent on collaborative ideation and reasoning, providing an interesting opportunity to study the evolution of the use of artifacts even before the storyboard construction; members will have to spend time suggesting possible uses, comparing the options presented, making decisions, and eventually sequencing the artifacts. This approach presents the need to explore the collaboration taking place toward building a shared understanding throughout the process.

## INVESTIGATING COLLABORATIVE STORYBOARDING

Towards understanding collaboration over storyboarding artifact templates, we conducted a study of novice designers. Of particular interest are the ways in which designers interact with design artifacts and communicate with each other during the activity.

### Participants

We gathered 21 students to take part in our study. All participants were actively engaged in conducting HCI

research or enrolled in a graduate HCI course at the time of the study. Their familiarity with storyboarding varied widely, though we do not believe this significantly impacted their manipulation of design artifacts.

## Materials

The participants worked in a closed office with a table and three chairs in the center. A video camera was mounted such that the whole table could be recorded. Two additional chairs were placed in the room for the observing investigators.
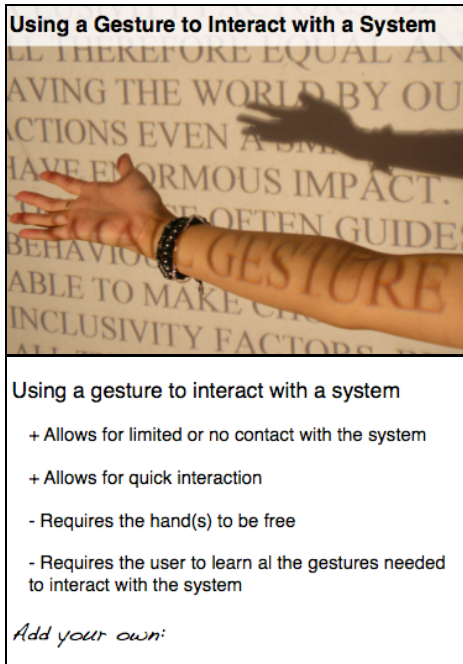


**Figure 1. The front of the cards had pictures illustrating the design feature along with labels (top). The back described the consequences of using the feature in a design (bottom).**

Thirty cards describing design features were scattered on the table (see Figure 1). The front of each card had a picture representing the feature along with a label. The back of the card had a claim for the feature. A claim is a reusable knowledge form that encapsulates the positive and negative impacts of a design feature [4,24]. Blank pieces of paper and pens were also provided, as well as an instruction sheet that explained the task, definitions for concepts such as claims and storyboards, and a prepared design problem.

## Procedure

The participants were randomly divided into 7 groups with each group having 3 people. Once the group was settled in the room and the video camera was turned on, they were given the instructions for the design task. Each group was asked to create a storyboard with 4-7 panels representing a system that would solve a given design problem. Each group was given a different design problem to solve. Upon completion of the storyboard, they were asked to write a narrative for the storyboard describing a usage scenario. While reviewing the instructions the participants were free to look at the cards and ask us the investigators questions regarding the task. Once they read and understood all the instructions they were permitted to start the design task. Each group was told they had 40 minutes, but we did not stop groups that went over the time limit. Two investigators were present throughout each study session. Both investigators took notes about the actions and things that were said by the participants. They only answered questions that related to the instructions. Any other questions were left up to the participants to resolve.

## Analysis

The video recordings of all the study session were converted into a digital file format and shared among the investigators. We took a grounded theory approach [23] to analyzing the data. We adopted the open coding technique [23] in which we identified categories that we began to observe upon close examination of the videos. Categories of analysis included two types. We looked at representational changes, which included searching, piling behavior, and storyboarding structure. We investigated communication mechanisms by analyzing suggestions, decision-making, sequencing, gestures, card placements, and utterances. Timing data was also collected. Each group video was analyzed by two coders who watched the complete videos and identified critical points of interest based on the categories they developed.

## MODEL OF COLLABORATION FOR STORYBOARDING

Studying the flow of storyboarding illustrates to us that there are important collaborative processes that take place. Like Tang and Liefer [25], we prefer to use a model to guide our thinking of our investigation. Since we took a grounded theory approach to the analysis, our initial analyses of the design sessions lead to the emergence of a model for collaborative storyboarding.

Our model suggests collaborative storyboarding may be defined as a process where designers, or *actors*, manipulate a *representation* of *artifacts* to articulate a usage scenario for a system (see Figure 2). To reach this goal, actors progress through three phases during their collaboration. The representation reflects the work that is done within each phase as it evolves.

The first phase, *exploring*, is marked by a state where actors are beginning to grasp and understand the design task ahead of them. As a consequence, there may be limited organization of the artifacts and actors focus on familiarizing themselves with the artifacts. In the second phase, *differentiating*, actors adopt a strategy to handle the artifacts. Typically, the strategy outlines the need for decision-making on the basis of some form of classification. The artifacts are subjected to the classification scheme and the results are reflected in the
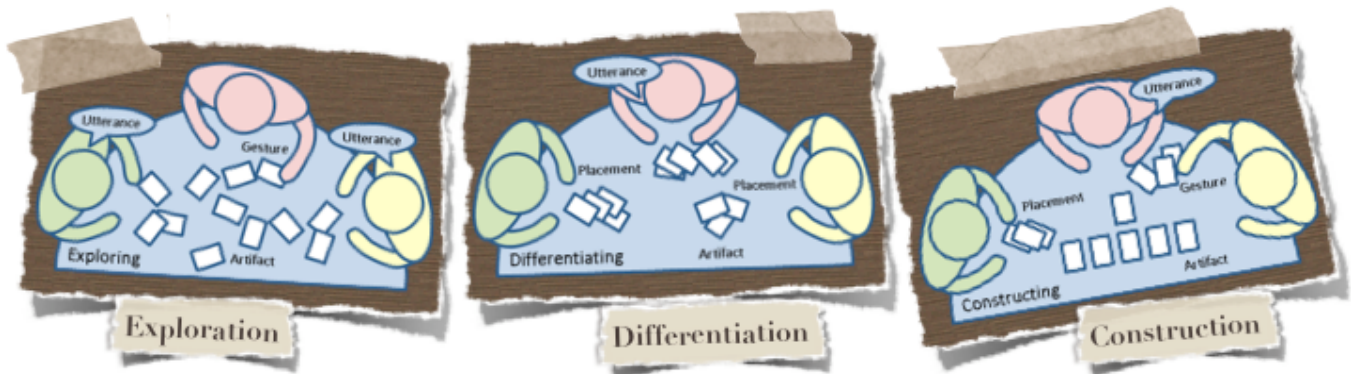
**Figure 2. A collaborative storyboarding model consists of actors that transition through phases of exploration, differentiation, and construction and revisit previous phases when needed. Actors leverage the artifacts through placements, gestures, and utterances.**

organization of the artifacts. The third phase, *constructing*, marks the beginning of the assembling of the artifacts to form a storyboard. Decision-making can continue to take place, while the organization of the artifacts is changed further to reflect the growing emphasis of the storyboard. Actors *transition* from one phase to the next as they progress through the task. It may be that they return to a previous phase, revisiting artifacts that were explored or changing decisions that were made.

Within each phase, *utterances*, *gestures*, and *placements* are used by the actors as communication mechanisms to move forward. Each mechanism serves to carry out specific activities such as sharing, comparing, deciding, and ordering artifacts. While these activities emerge in certain stages, they can continue to occur for the duration of the storyboarding session.

Unlike the perspective taken by Bailey et al. for multimedia design with respect to storyboarding [3], our model does not include a brainstorming phase. Because artifacts are provided to the actors, there is no additional need to brainstorm on new artifacts. Additionally, brainstorming regarding the use of artifacts is accounted for in the exploration phase. We also intentionally excluded iterations on the storyboard from the model, as this relates to the nature of the design rather than that of the collaboration. However, we do mention actors can revisit previous stages when needed.

**RESULTS**

In this section we present the general characteristics of each phase through the data we collected. We focus on trying to highlight the range of activity that took place as well as the distinctions between the phases. We determined a new phase started when we first observed activity related to the phase. Our results are described below and summarized in Table 1.

The exploration phase of the activity started at the beginning of their session. On average the groups spent 5 minutes and 7 seconds, or 11% of their time, in this phase. Group 4 spent just 50 seconds in the phase while group 3

spent 7 minutes and 46 seconds in the phase. The participants spent time familiarizing themselves with the scattered cards presented to them in various ways. We counted activity such as touching a card or reading the label out loud as ways of discovering and sharing cards. Looking at the total number of times a card was explored, we found on average 86 cards explorations took place, ranging from 56 by group 5 to 102 by group 3.

When we began to observe the groups making decisions regarding the cards and beginning to impose some form of organization to the cards, we marked it as the start of the differentiation phase. On average the groups spent 12 minutes and 12 seconds, or 28% of the session, piling, grouping, clustering, comparing, and deciding—key activities in differentiation. Group 2 spent just 27 seconds in the phase while the upper bound was set by group 1 with 13 minutes and 55 seconds. On average each group divided their cards into 3 piles or groups. Group 1 had 2 piles while group 5 had up to 6 for their cards. We also observed the continuation of exploring activity in the differentiation phase for all the groups. For example, group 4 explored an additional 86 times.

The construction phase began when participants placed cards in a region with the intention of starting a storyboard. An average of 25 minutes and 38 seconds, or 61% of the time was spent in this phase. Group 1 completed the phase in 13 minutes and 4 seconds while group 7 spent 56 minutes and 2 seconds. The final sizes of the storyboards varied a lot. Group 1 had a storyboard with 5 cards while group 5 had 14 cards. There was considerable shifting in the number of cards being placed in the storyboard. At one point the storyboard for group 3 had 13 cards in it. They eventually narrowed it down to 9 cards. Group 7 also had up to 17 cards before they finally settled on 12. Note that we had asked for the storyboards to have 4-7 panels, but an average of 12 cards were used because certain cards were grouped together within the same panel. As with the differentiation phase, we also observed exploration and differentiation related activity in the construction phase, although this was less.

| | Exploration | Differentiation | Construction | Total |
|---|---|---|---|---|
| Average Time Spent | 5:07 min. | 12:05 min. | 26:38 min. | 43:50 min. |
| Average Times Cards are Explored | 26 | 48 | 12 | 86 |
| Average Number of Card Groups/Piles | 0 | 3 | 1 | 4 |
| Average Number of Cards in Storyboards | 0 | 0 | 12 | 12 |

**Table 1. The average time, explorations, group/piles, and storyboard size in the three collaborative storyboarding phases.**

These results serve to demonstrate that there are key actions that emerge at certain points during the sessions—defining the different phases of our model. We also notice that the phases are not completely independent of each other. In fact, the subsequent phases tend to build on the previous phases. Based on these results, we delve further into the ways the cards are manipulated and the activities that the participants carry out in our discussion.

**DISCUSSION**
To fully investigate the nature of collaborative storyboarding we wanted to better understand the intricacies of what was actually taking place within each phase. First, we set out to characterize the broader changes that were taking place on the surface of the table with respect to the cards, expecting this would provide additional reason to draw lines between the phases. Second, we intended to inspect the specific activities and communication mechanisms that facilitated progress through a phase. Our discussion of these two issues is aimed at demonstrating how the participants followed our collaborative storyboarding model.

**Representational Changes**
Of specific interest to us was the offloading of internal knowledge of participants onto the external environment in the form of a representation. DCog was used to facilitate our understanding of how artifacts were used to preserve information in the environment. We proceed to describe our findings and provide examples from the design sessions.

First, we must explain a subtle difference in the way we treated our analysis. Perhaps it would be more common to scrutinize the organization of the representation—in our case the storyboards—created by the groups in terms of DCog. However, we adopt the perspective that the organization is the representation. In essence, we treated the arrangement of the whole set of cards on the table from the beginning to the end of the task as an evolving representation.

*Exploration*. In the exploring phase, the state of the representation remained significantly unchanged in logical terms across all the groups, as shown in Figure 3. Group 3, in particular, best exemplified this type of behavior. For an extended period of time, the members looked at the cards without necessarily touching or talking about them. This activity was accompanied at times by the out-loud reading of feature labels on the cards. When participants picked up

cards for closer inspection, they placed them back into the same location. Through this example and the behavior of the other groups we see that the cards remained generally scattered in the middle of the table—a sign of minimal offloading onto the representation due to the lack of decision-making. Instead, participants relied more on passing information directly between each other to share discoveries.

The fact that all the cards were scattered across the surface at once made it hard to understand or even see all the cards. A participant from group 1 noted that he was trying to create stacks because he needed to reduce the clutter to be able to see all the cards. In this way, the representation of the cards was a motivating factor in beginning the process of card differentiation.



**Figure 3. Collaborators from group 6 in the exploration phase. The cards remained scattered as group members familiarize themselves.**

*Differentiation*. As noted in our results, the representation began to exhibit clusters or piles as a result of decision-making activities in the differentiating phase (see Figure 4). Throughout the process we observed a mix of both scattered cards and cards that were explicitly arranged. This was mainly due to the fact that even when differentiating began, the process of exploring continued (shown by the scattered cards).

For example, group 1 leaned more toward maintaining the scattered arrangement by only moving a limited number of

cards they thought they would use in their storyboard to the side of the table after explicit discussion and decision-making. The unwanted cards remained scattered. In this group's case, the cluster on the side of the table was directly forming the basis for their storyboard. Thus, information was first passed between team members and then offloaded onto the representation.



Figure 4. Group 5 in the differentiation phase. A group member places a card onto one of the five existing piles. A few scattered cards are yet to be categorized.

A different strategy was utilized by group 4, which had 3 piles. Although the whole representation was being shared, regions of the representation became semi-private. As the participants took cards from the center of the table, they made a decision and then placed the card in one of the piles close at hand. Therefore, not all the members were initially aware of the meaning of piles in other regions. We found that there were initial moments where the members did not immediately explain their decision, leading to potential information discrepancies. This was remedied when another person attempted to access someone else's region, revealing the meaning of the pile. Contrary to the previous example, information was offloaded onto the representation first and only fully passed on to the others after discrepancies arose.

Transitioning into the construction phase depended on whether the group had shared and considered enough cards with each other and made decisions about them. The representation reflected to the members that they were at an adequate level of familiarity with the cards to commence construction because of the nature of the modifications made (i.e. cards were organized in some form that reflected enough decisions were made). Group 2 was the exception to this. They spent only 27 seconds in the differentiation phase before one of the members proceeded to immediately start creating the storyboard. In their case very little had changed in their representation before a member proceeded to enter the construction phase.

*Construction*. During the construction phase we noticed the representation tended to have more distinct regions by that point—a reflection of the activities that took place previously (see Figure 5). We found cards could remain scattered, portraying the continuation of exploring activities. Piles and clusters also existed in various regions as a result of differentiating. The construction phase brought about a new area of the representation dedicated to the creation of the storyboard. Most of the groups began their construction activity on the side of the table where no one was sitting so that all the members could see it. The degree to which these regions existed reflected the amount of phase-related activity that was taking place.

In general participants continued to move fluidly between sections of the representation if they existed. For example, the representation for group 4 well into the construction phase had a pile of rejected cards on the corner of the table, a few scattered cards in the middle of the table and arranged cards on the side of the table for their storyboard. At one point, a member picked up a card from the middle of the table, held it up above the storyboard and said, "*use of indicator…do we need this?*" Another participant responded, "*not much anymore*." The member then threw the card into the reject pile across the table. While this demonstrated an increased reliance on offloading information onto the representation to reflect a decision, this also portrayed the transitions that can still occur during construction—the participant explored the scattered cards and then differentiated by posing the question.

Group 2, which moved to the construction phase quickly, spent considerable time making such transitions while creating their storyboard as they had not previously made the decisions in the differentiating phase. In fact, at one point one member who controlled the storyboard portion did not engage in the differentiating with the others. For some time this resulted in the group having a split representation where information was externalized by the others, but not received by the member working on the storyboard due to all of them engaging in different phase-related activities, leading to some confusion and revision of the decisions being made.

When we looked closely at the storyboard portion of the representation, we noticed several different ways in which the storyboards were structured. Generally, the cards were laid out horizontally next to each other to indicate progression through the usage scenario. However, we found two interesting structures that emerged within the storyboard. There were many instances where participants found it appropriate to combine cards together to symbolize that the features were working together. Typically, when features were combined, the cards would be placed next to each other or overlapping slightly. Group 5, for example, had 5 panels that contained 2 or more cards within them and group 7 had 3 such panels. Groups 2, 4, and 6 had 2 panels each.

Another emergent structure involved the creation of alternative pathways within the storyboard. Group 4 tried to portray the alternative paths by using two dimensions. They placed cards horizontally to illustrate the sequential actions and vertically whenever alternative actions could take place.



**Figure 5. Group 4 in the construction phase. A group member sequences the cards within the storyboard. The cards in the "throw away" pile have been ushered to the corner.**

*Summary*. Our analysis with respect to DCog demonstrates that the construction of the storyboard is inherently very distributed. The characteristics of the card representation provide impetus behind our effort to emphasize the distinctions between the three phases of our model. We realize as participants progress through the phases, the emphasis on the representation increases with more information being offloaded onto the representation. This is most apparent in the transition from the exploring phase to the differentiating phase. Those who take part in collaborative storyboarding sessions need to manipulate an artifact representation with ease to be able to handle the large number of possible ideas that may be generated through combinations, relations, and sequences of artifacts. Even the smallest piece of information may lead to large changes within the representation. With an increased number of artifacts to deal with, this task might get harder for the team.

**Communicative Activities**
While we found out that the representation played an important role during the collaborative storyboarding sessions, we also wished to identify the specific activities that supported team. Thus, this analysis focuses on the individual actions that move the team forward. Our initial analysis had quickly led us to believe that gestures, utterances, and card placements were key to the communication taking place. Because of the constant usage of these communicative mechanisms, we decided to continue our analysis through the use of common ground.

We proceed to describe how gestures, utterances, and card placements play a vital role in the acts of suggesting, decision-making, and sequencing. While we cannot provide examples of all the mechanisms being used for each act due to space limitations, we hope to be able to demonstrate the range of acts they are used in.

We found that the information was being shared both explicitly and implicitly among the members. Explicit communication refers to communication that is intentional, where a person explicitly tries to convey or elicit information to or from a receiver, while implicit communication is what occurs when the sender unintentionally broadcasts to collocated receivers that may or may not receive the information [7,30].

*Suggestions*. By far, the most common activity that took place was the act of suggesting a card to another person or the whole group. We were able to identify an average of 16.2 suggestions per group. Group 2 set the minimum at just 7 instances and group 1 the most with 23 cases. Participants would discover cards and naturally want to offer them as potential solutions to the problem at hand. Often we observed participants start by pointing, touching, nudging, holding, or flipping cards without making utterances as a way of implicitly demonstrating a card was being looked into. When suggesting the card to someone else the act would become more explicit. One common method was to read the card's label out load for the rest of the group to hear and consider. The following example from group 4 demonstrates the use of placements and gestures as a mechanism for suggestions:

RB:    *[nudges then picks up a card, flips to read the back, places card centrally and makes a rigid pointing gesture]*
AA:    *[picks up card and places it near SV]*
SV:    *[picks up card and tosses it on the 'keep' pile]*

Communication in this instance was facilitated by the implicit communication that occurred through the gesture of nudging and then picking up the card and flipping it over for a moment. Then, placement of the card into a central location drew the explicit attention of another team member, with the following pointing gesture proposing the card to RB. This teammate then acknowledged the gesture by picking up the card himself. A proposition was made to SV by placing the card in his local area. SV accepted by picking up the card and placing it in an area recognized as the "keep" pile. Without a single word exchange and within the span of 6 seconds two proposition cycles had taken place.

*Decision-making*. Another frequent activity was the act of deciding what card to use in the creation of the storyboard. The process of deciding involved comparing and categorizing cards into piles or groups. As observed in the previous activity, many participants first chose to carry out the activity on their own, comparing items in their own

space by turning cards over and holding or placing them side by side to study the similarities and differences. Some placed two or more cards in a stack to display a relationship between those particular cards. These are ways of implicitly sharing the comparison act and results with teammates without explicit conversation. On average 3.5 comparisons were observed in the groups. Group 7 had 1 instance while group 3 had the most with 7 comparisons. The following example from group 3 demonstrates how an explicit comparison took place with the use of utterances:

RW:    [places two cards, claim-up on the table in a central area]
       "I think these…"
       [points to cards, one with each finger, then retreats]
       "two items are…"
SP:    [touches the edge of one of the cards and pauses]
RW:    "very similar…"
       [points to cards with fingers]
       "to each other."

In this conversation snippet RW proposed two cards for deeper consideration through side-by-side comparison. She used the positioning to symbolize this comparison and pointing to draw further focus to these two cards. SP acknowledged this proposition and accepted it by placing her hand on one of the cards to indicate her engagement.

The next example from group 6 portrays placement being used to explicitly indicate the decision being made with respect to a card. As participant BB holds a card in his hand, the following occurs:

ME:    "Looks like that would be part of the continuous notification, right?"
BB:    "Yeah."
       [places 'continuous notification' card down so that it touches the group of cards]
ME:    [moves another card in the group slightly so that its corner overlaps the 'continuous notification' card]

In this example, ME proposed that the card BB held was related to another card in the "keep" pile. BB accepted by placing the card on the table so that it just touched another card in this pile. Then, ME accepted this acceptance and reinforced the relationship by nudging an adjacent card ever so slightly so that it partially covered the new card. Here, utterances, placement, and nudging were all core aspects of achieving this communicative act.

*Sequencing.* An activity core to the assembling of the storyboard itself is sequencing, in which the group tries to formulate the order of the cards. This activity took on many forms. In group 6, the initial version of the storyboard was constructed solely by moving cards around the table without the use of words. Most groups went through several stages of the storyboard, repositioning cards and adding or removing a card whenever appropriate—focusing more on explicit communication. On average cards were added or

removed 16 times. Group 1 did this just 9 times and group 2 did the most with 25 times. Often group members would create the storyboard piecewise. In the following group 3 example, a portion of the narrative was identified:

AS:    "So it's going to be a notification…"
       [shifts 'sporadic notification' card up on the table]
       "which…"
       [shifts 'blinking light' card and 'textual notification' cards into a second row beneath 'sporadic notification' card]
       "will be…"
       [moves 'tactile notification' card into the second row with previous two cards]
       "all three... going into…"
       [shifts two more cards into rows three and four]
       "something like this: Arrow…"
       [gestures an arrow at upper third of the storyboard]
       " arrow ..."
       [gestures an arrow at middle of the storyboard]
       " arrow "
       [gestures an arrow at bottom third of the storyboard]
SP:    "Yeah."
RW:    "Mm hm."

Above, we see how AS took some cards that were in the "keep" pile and worked them into a verbal scenario as he positioned them in a linear order. Placement and precise timing of his utterances helped to communicate his proposition effectively. The placement of three cards in a row gave the statement "all three" an identifiable meaning to both attending teammates. The gestures signifying the arrows were used to further emphasize the sequence to the others. Perhaps the only scenario-related word in this example is "notification", yet AS communicates effectively without relying on scenario-specific content, relying on the storyboard itself to convey information. Members SP and RW replied with acceptances in the form of utterances.

Group 3 demonstrated modifications that can take place to the sequence even when it seems the storyboard is complete:

AS:       [nudges card away from storyboard slightly]
SP & RW:  [writing scenario]
AS:       [places hand on card and moves it farther away]
SP & RW:  [holding the 'relating notification to prior information' card and focusing on that feature]
AS:       [moves card farther from storyboard towards throw away pile]
AS:       [picks up feature and moves it into trash pile]
SP & RW:  [writing scenario]

Just before this dialogue, team members SP and RW had agreed that they had completed their storyboard. However, as we see in the example, through a series of motions, AS continued remove a card from the storyboard and place it into a "trash" pile. While we are not necessarily sure if he

was seeking feedback from the others, we find it interesting that he decided to not just remove the card, but also place it into the "trash" pile to reflect the decision-making activity.

*Summary*. Collaborative storyboarding is a process marked by rich communicative mechanisms. The use of common ground allows us to critically analyze how the individuals contributed to the larger task at hand. We find the participants need to rely on the use of gestures, utterances, and placements to suggest, decide, and sequence throughout the design session. It is interesting to note that although these acts may emerge in a certain phase, they do not necessarily end. For example, suggesting a card is quite a frequent act in the exploration phase, but the act continues well into the differentiation and even the construction phases. Our last example where a participant modified the storyboard after it was completed serves to demonstrate that decision-making, while it emerges in the differentiation phase, can still continue in the construction phase. This does lead us to believe that participants can always return to a previous phase, even if it is for a brief moment.

## CONCLUSION

This paper introduces an approach to prototyping—collaborative storyboarding—that leverages the use of artifact templates and staged design to engender a shared understanding among designers about the nature of the problem and potential approaches to address it. A study investigated the group interactions that take place during collaborative storyboarding sessions, toward identifying points of successful communication and progress. A three-phase model—exploration, differentiation, and construction—matches the way that successful teams naturally align with and engage in collaborative storyboarding. A DCog analysis revealed landmark states within the evolution of the representation of artifacts, and a common ground analysis showed the actions in the phases that were ushered changes in the representation. Three key findings, presented here, provide guidance for future research in the area. For each finding, we reflect upon ways that intervention—through a moderator, via guidelines, or with tool support—could help maximize opportunities for success.

*Collaborative storyboarding drives increased shared understanding*. As noted by Minneman, the overall goal of collaborative design lies not only in accomplishing a task but also in creating a shared understanding [18]. Presentation of a breadth of potentially unfamiliar ideas (through artifact cards) combined with the structure and space limitations (necessary for a storyboard) opens the door for rich collaborative creation and coordination of meaning and understanding. The artifacts of collaborative storyboarding rise to the occasion, catalyzing designers' goals of jointly familiarizing themselves with the range of possibility, identifying categories of group interest, and creating an articulate narrative—goals that closely correspond to the phases of the model. As we have seen

from our data, this meaning and understanding is created through artifact interaction and confirmed through the progressing state of the representation. Collaborative storyboarding is not just a sequential form of collaboration, but also a layered approach with aggregation of knowledge from phase to phase.

*Joint interaction within the collaborative storyboarding phases of exploration, differentiation, and construction yield effective information exchanges, while disjoint actions introduce confusion*. As noted throughout the study, collaborators built cooperative understanding when they were working within the same phase. There were instances, however, where the creation of semi-private regions coupled with the movement of some members into a new phase led to a breakdown in the shared understanding. This activity gave rise to instances where one or more members were unaware of portions of the current representation and required that the other group members' to bring them up to speed. In such instances, a moderator could ensure that all collaborators are aware of a transition, or a tool could summarize key transition points and accomplishments for group members and sub-groups.

*Adequate group efforts within each collaborative storyboarding phase lead to shared understanding for success at later phases, while abbreviated efforts result in breakdowns due to incomplete or inadequate levels of understanding*. As evidenced by the study results, groups typically spent about twice as long in a given phase as in the previous phase. On rare occasions, however, rapid progression through a phase occurred, which resulted in periods of confusion in subsequent phases, followed by repeated backtracking to generate an adequate level of understanding to complete the phase. Intervention, say by a moderator, could advise the group to complete the current phase prior to advancing to the next. Likewise, a tool could enforce the process on novices, or highlight milestones within the phase for experts, to show benefit in developing deeper understanding within a phase.

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