Experiential Augmentation: Uncovering the Meaning of Qualitative Visualizations when Applied to Augmented Objects

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ABSTRACT
As we move toward commercial usage of ubiquitous computing and augmented reality (AR), it is important to think about how computing should communicate with us when it is distributed in our environment. This paper proposes that qualitative indexical visualizations based on learned understanding of physical phenomena (Experiential Augmentation) can enhance our interaction design language and aid digital interfaces in communicating in a real-world context. We present a study that gathers data on how participants interpret such visualizations, and propose a model with which to analyze their responses. Finally, we also give a set of design recommendations for those interested in creating similar augmentations.

Author Keywords
Indexical Visualization; Qualitative Visualization; Augmented Reality; Ubiquitous Computing

ACM Classification Keywords
H.5.1 Multimedia Information Systems; H.5.2 User Interfaces

INTRODUCTION
Charles Sanders Peirce explained that signs fall into three types: icons, symbols and indexes [11]. Icons and symbols are heavily used in screen based interactions. However, as we move into a world of ubiquitous computing, researchers have argued that to transcend screen based interactions, indexical visualization could be used [2,5] to offer different affordances for understanding.

Indexical visualizations carry a causal, qualitative connection to the phenomena or properties they visualize; they are part of the way we understand the natural world around us. Smoke for example, is an indexical sign of fire; the movement of a flag is an indexical sign of how windy it is. Indexical visualization is used in the fields of tangible computing and ambient displays [10,15] for data visualization; Natalie Jeremijenko's "Live Wire: dangling string" was one such example [14].

This research investigates whether designers working within HCI can borrow understood indexical signs for use as building blocks for data visualization. For example, we understand how full a container is by how heavy it is, which leads us to question whether we could also understand how full a USB drive is by giving it the illusion of weight when it is filled with data. This example 'borrows' our understanding of weight, and through indexical visualization, applies the meaning of weight change to a new object: digital data. In our research, we explore this borrowing of understanding through alteration of physical properties, and envision applying it through augmented reality, to connected objects in the context of ubiquitous computing [14] —what we call Experiential Augmentation. We then further propose a framework with which designers are able to analyze the results of their explorations.

The future of ubiquitous computing is filled with objects with a physical form, and an invisible digital side [21,22]. Designers are currently visualizing the digital primarily through the use of icons and quantitative symbols. However, Experiential Augmentation could allow connected devices to make their invisible actions explicit through same indexical and qualitative vocabulary as the natural world. This paper also proposes that since humans are already trained to filter in and out the qualitative vocabulary of the natural world, using this vocabulary in connected objects is a step toward creating calmer, less intrusive ubiquitous technology [13].

Experiential Augmentation is envisioned to be executed through augmented reality [18,23]. Previous work has incorporated similar ideas of alteration of physical properties in objects for visualization [1,3,10,12,19,22] Lindlbauer's work on changing the appearance of objects through modifying surroundings is especially relevant as it uses digital augmentations to alter real world objects for the purpose of visualization. While Lindlbauer's research focuses on the execution of such visualizations, this paper

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extends Lindlbauer's work by providing a general framework with which to analyze the ways viewers interpret the meanings of altered physical qualities. It aims to help designers better understand how to use Experimental Augmentation as building blocks for communicating properties and state changes in future objects and systems. Finally, we believe our research adds to the sound argument for less experience-impeding versions of augmented reality, and avoids overcrowding a user's field of vision [14, 25].

STUDY

Study Introduction
Experiential Augmentation uses our learned understanding of physical phenomena as building blocks for data visualization in objects. The next section of this paper describes a study carried out using a series of images and videos, to explore the ways in which participants interpret the meaning visualizations created with altered physical qualities.

Study Variations
Our study consists of seven different alterations to the appearance of an object's physical characteristics: losing weight (floating), gaining weight (sinking), loss of rigidity, loss of opacity, loss of color, sound of flow, sound of shaking; each alteration is applied to three different objects. One of the objects, a control, usually a block of wood, was chosen as it was assumed to have no invisible information to visualize. Each variation tests whether alterations of an object's physical characteristic would help participants interpret invisible underlying information. Initial work on the topic of altering shadows to give illusion of weight changes in an object was published as a work in progress paper [6]; the examples in this paper formed the basis of the current body of experiments.

Survey
Our variations were tested through a survey. The survey focused on understanding the potential range of interpretations for each variation in the study. As such we relied on open ended responses to build this corpus of interpretations. For each object/augmentation combination, participants were asked questions in two stages: (1) to check whether the visualization was clear, participants were asked "What is happening to the object / What is the object doing?" And then (2) to test interpretation given a correct identification of altered physical state they were asked "You may have noticed that in each image one object is (floating). What do you think the object is doing this? What is the object trying to communicate to you?". We then categorized each explanation into one of 5 meaning categories. Patterns from the meaning interpretations were then used to create a set of design recommendations for those interested in designing for Experiential Augmentation. The survey was sent to 40 participants, ages ranging from 18 to 65, with an estimated median age of 35. Occupations ranged from students to working professionals to retirees, of varying backgrounds and nationalities, recruited via our personal networks. Informal convenience sampling was considered appropriate as our focus was primarily to explore the diversity of interpretations of Experiential Augmentations.

Context specificity
In our studies, objects were not placed in a defined context. This is because a specific context would add new variables to understanding meaning of the object: the context itself is at least one, if not more objects, carrying their own meanings. To understand the combined meaning of context and augmented object, we must first understand the meaning of the augmented object alone, then see how it changes when placed in different contexts.

Pictures and Video
Our surveys used pictures and video rather than delivery through AR devices. This choice was made to prevent the delivery method from influencing the meaning of our visualizations. We wanted our participants to interpret the visualizations as if the augmented physical phenomena were truly happening to the object. The influence of delivery devices on the meaning of Experiential Augmentations will be investigated in future research.

The following section will discuss the experiments as well as the majority consensus interpretation for each experiment.

Experiment 1: Float

Figure 1. Float example: USB drive with shadows altered to give a sense of weightlessness.

The *float* series of experiments tests how perceived decreases in weight relate to participants' understanding of a wood block, debit card and USB drive. Shadows were altered on images of objects to produce an effect showing the objects 'floating' (Figure 1).

Float Results
In general, floating had an emotionally positive and active connotation. Regardless of the type of object, participants responded that the object 'wanted' to be picked up, or that it

was making itself available to be used. This availability was either interpreted as an affordance, “a floating drive is easier to pick up”, or a personification “the drive is asking to be picked up”.

Experiment 2: Sink

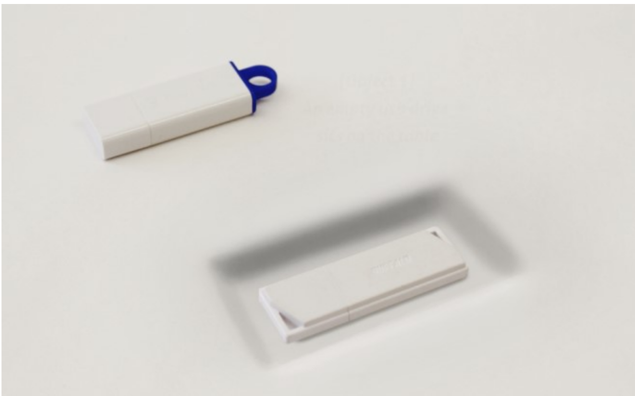

Figure 2. Sink example: USB drive with surrounding shadows/shading altered to give a sense of sinking into the surface.

The *sink* series of experiments tests how perceived increases in weight relate to participants’ understanding of a wood block, debit card, and USB drive. Shadows and shading were altered on images on objects to give an appearance of ‘sinking’ (Figure 2).

Sink Results

While the float series of experiments were interpreted as a general call to action, the sink series of experiments were linked more closely to the changes in the functionality and material of their associated objects. Participants suggested that, for example, the sinking debit card was showing that they were in debt, and should not spend money, and that the sinking USB drive was heavy with data, and should not be used. As expected the control experiment of a sinking block of wood, while looking heavier, could not be linked to any state or underlying process change.

Experiment 3: Rigidity Loss

Figure 3. Rigidity loss example: business card losing rigidity.

This series tests how rigidity loss relates to participants’ understanding a blank card, a business card and a debit card. Images were shown (Figure 3) of a card losing its rigidity and bending away from the viewer.

Rigidity Loss Results

Some participants suggested that the blank card in the control condition may be losing rigidity to prevent itself from being used, but as expected a majority could not find meaning in the rigidity change. Participants interpreted rigidity loss in a business card as being connected to the person the card describes. Some thought the card owner was untrustworthy, or even dead. Others thought the owner had moved on to new types of work and the information on the card was outdated. Finally, participants interpreted the change in debit card rigidity as an effort by the card to reduce its own usability, to stop the owner from swiping it because of lack of funds.

Experiment 4: Fade

Figure 4. Fade example: fading smart phone.

The *fade* series of experiments tests how increased transparency relates to participants’ understanding of a wood block, debit card, and smart phone. Images were shown (Figure 4) in which the object became progressively more transparent.

Fade Results

Participants interpreted the wood block fading as a loss in structural integrity, a sign that the wood was rotting, or of bad quality. A debit card fading was also seen as a warning not to use the card, with responses relating the fading to a low monetary balance. Finally, the smartphone majority consensus related to fading battery power, although there were other interpretations of the phone being disabled, or in ‘do not disturb’ mode.

Experiment 5: Color loss

Figure 5. Color loss example: Apple losing color.

The *color loss* series of experiments tests how the loss of color relates to participants' understanding of a wood block, discount card, and apple. Images showed the object losing its color, becoming grayscale (Figure 5).

Color loss results

Similar to opacity loss, color loss on the wood block was linked to loss in structural integrity and usability as a building material. Color loss in discount cards were linked to a loss of validity. Finally, color loss in an apple was interpreted as an indicator of expiry of the fruit.

Experiment 6: Sound of flowing

Figure 6. Sound of flow example: still frame from USB plug video.

The *flow* series of experiments tests how the sound of water flowing relates to or enhances a participant's understanding of an action involving plugging in a wood block, a smart phone, a USB drive. Participants were shown a video of the object being plugged in, coupled with the sound of water flowing [4, 20].

Flow sound results

Most participants identified the sound as a flowing of electricity in the case of the wood block and smart phone; the wood block was interpreted as containing electronic components. The flowing sound was identified as data in the case of the USB drive. However, participants also noted that the specific identifiable sound of water flowing was actually distracting and uncomfortable when coupled with the usage of electronic devices.

Experiment 7: Shake Sound

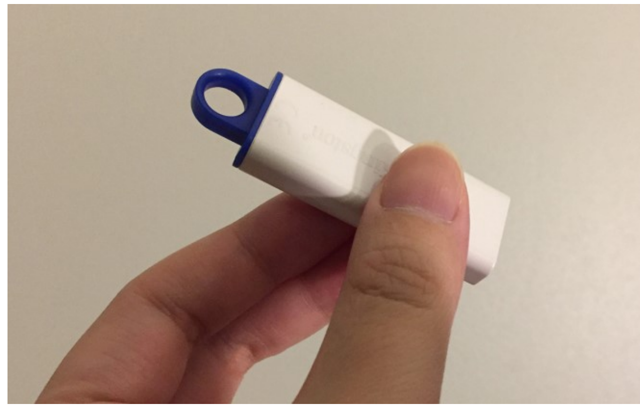

Figure 7. Shake example: still frame from USB shake video.

The *shake* series of experiments tests how the sound of shaken objects relates to or enhances a participant's understanding of what is contained in a wood block, debit card, and USB drive. Participants were shown a video of one of the three objects being shaken, coupled with the sound of coins being shaken in a bottle, and a salt shaker being shaken.

Shake sound results

A majority of participants thought the woodblock was just a container holding objects, and that no enhancement or augmentation was made. Participants thought the heavier rattle of the coin sound, coupled with the debit card being shaken signified more money in the bank, while the softer sound of salt signified less money. Similarly, the different sounds signified different quantities of data within a USB drive. Some participants suggested a possible improvement to the USB portion of the experiment is to use a more data sounding effect.

OBJECT / AUGMENTATION / MEANING TYPE

Analyzing the survey results, it became clear that each participant interpretation could be broken down into three building blocks:

1. The participant's subjective understanding of the *object*.
2. The participant's subjective understanding of the *augmentation*.
3. The type of meaning delivered by the object/augmentation *combination*.

Following are example observations that pointed to the importance of the three categories.

Interpretation of the object

Originally, objects that we thought had no underlying invisible processes were used as a control in testing. However, participant interpretations of the wood block experiments show that even this could be perceived as having invisible processes. When participants saw a block of wood as something that was to be used in construction, for example, the wood suddenly had an invisible process of structural decay that needed to be made visible. On the other hand, when participants could not understand the purpose of the wood block, they were also not able to interpret meaning in the augmentation. This means that the participants held various schemas [17] of "wood" in their minds, and would default to whichever definition the augmentation was most concretely linked. A piece of wood floating, for example, had no concrete link to any definitions of wood for most participants, so they struggled to think of an invisible process that matched the representation. However, discoloration reminded participants of the materiality of wood. Thus, participants were able to switch to a definition of wood as construction material, then interpret the wood losing color as an indicator of structural weakness.

A final interpretation of an Experiential Augmentation firstly relies on the participant's understanding of an object, and a single participant can have multiple understandings of the same object. This idea is supported by the concept of multistability [7].

Secondly, since the object is like a canvas on which the augmentation is placed, the participant's understanding of the object influences their understanding of the augmentation. In other words, the definition of the object itself is part of the message that is being conveyed [16].

Augmentation

Understanding of the augmentation itself is the second building block of interpreting the meaning of an experiential augmentation.

Past experience / Pop culture

Participants drew from learned understanding both from the real world and the digital world in their interpretations. In the fade series of experiments most participants thought the phone fading was a sign of loss of power, reflecting the real-world phenomenon of electronics fading when out of battery. However, a smaller set of participants thought the phone was asleep, reflecting a more screen based metaphor of a faded control being inactive.

An interesting extension to the usage of learned understanding is that a few participants drew from pop culture for their interpretations. One participant was reminded of the movie *Back to The Future* when looking at the fading phone, saying that in the movie, objects fade because their past has been altered.

These responses point to the importance of understanding and drawing from the participant's learned experiences when building an Experiential Augmentation.

Type of meaning

Analysis of survey results led us to categorize interpretations of meaning into four overall types.

The categories used to structure test results were *metaphor*, *personification*, *physical affordance*, and simple *notification*.

The first two categories—metaphor and personification—are simplifications of Lakoff and Johnson's metaphor categorizations from their work *Metaphors We Live By* [9]. Lakoff and Johnson's original metaphor categories were orientational, structural and ontological. However, Lakoff and Johnson's categorizations sometimes overlapped. It was also sometimes difficult to discern from survey responses whether participants were interpreting metaphorical meaning from augmentations, or something simpler, such as seeing the augmentation as eye-catching, and therefore a 'simple' notification. In order to not over-attribute understanding on behalf of the participant, we used a simple *notification* category for responses that did not explicitly demonstrate metaphorical understanding, and a *metaphor* category was used for those that did. In addition, Lakoff and Johnson's categorizations describe personification as a type of ontological metaphor. However, for the study, *personification* was given its own category as it was the type of metaphor that appeared most often. Finally, the *physical affordance* category was created when we noticed that augmentations, especially those that altered the physical form of objects, were sometimes viewed as physical affordances [8].

Following are descriptions of each category:

Notification

Responses that understood augmentation as calling attention to the object, but without a deeper metaphorical comparison. For example, "the phone is becoming transparent to tell me it is switched off".

Physical affordance

Responses that understand augmentation by reading how physical qualities affect interaction. For example, "the phone is fading out and becoming harder to find, so that I don't use it as much".

Metaphor

Responses that demonstrate the linking of invisible processes to more concrete entities. For example, "the USB drive is sinking, because the data inside is so heavy", demonstrates the metaphor of data as a physical thing with weight.

Personification

A special application of metaphor, that thinks of objects as living things. For example, "the USB drive is sinking into the table to hide from me, so I don't use it".

A MODEL FOR ANALYSING EXPERIENTIAL AUGMENTATION

We created a triangular model to formalize the relationship between object, augmentation and meaning type.

1. The first corner of the model represents the viewer's understanding of an object.
2. The second corner of the model represents the viewer's understanding of the Experiential Augmentation.

3. The final corner of the model represents the type of meaning being interpreted by the participant.

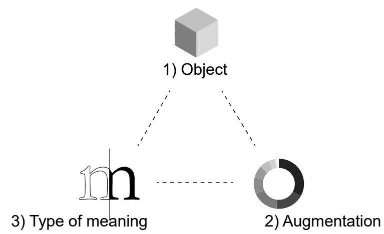

Figure 8. Model formalizing the relationship between object, augmentation and meaning type.

Example applications of the model

In one *sink* experiment, the area around a USB drive was re-shaded to create the illusion of the drive sinking into the table. For this example, participants either interpreted the drive as a general electronic device, or a more specific container of data.

As for the visualization, it was interpreted as either the USB drive sinking into the table from its own weight, or that there was a hole in the table, which the drive happened to be sitting in.

Finally, for the type of meaning, participants had a range of interpretations, from metaphor to personification to notification.

Each combination results in different interpretations of the augmentation. Understanding the drive as *a container of data*, the augmentation as *sinking into the table*, and the meaning interpreted through a metaphor of *data as a physical thing*, participants interpreted the overall meaning as the drive sinking into the table because it was heavy with data (Figure 9).

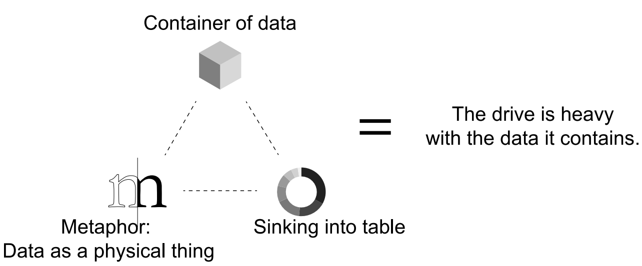

Figure 9. Model resulting in interpretation: the drive is sinking into the table, heavy with data.

Alternatively, when the drive was seen as *a nonspecific general device*, the augmentation as *a hole in the table* that the drive happened to be sitting in, and meaning was interpreted through the category of *personification*, the participant thought the drive looking cozy in its hole, and in its correct location (Figure 10).

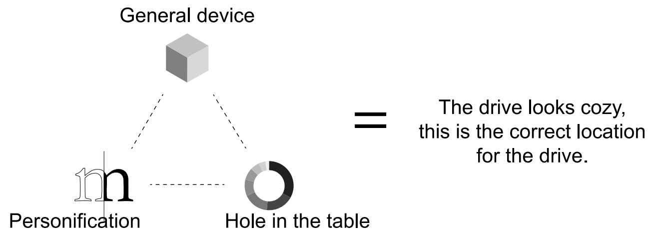

Figure 10. Model resulting in interpretation: the drive looks cozy, this is the correct location for the drive.

When the drive was seen as a nonspecific *general device*, the augmentation as *a hole in the table* that the drive happened to be sitting in, and meaning interpreted through the category of *affordance*, the participant thought the drive looked embedded in the table and physically difficult to pick up (Figure 11).

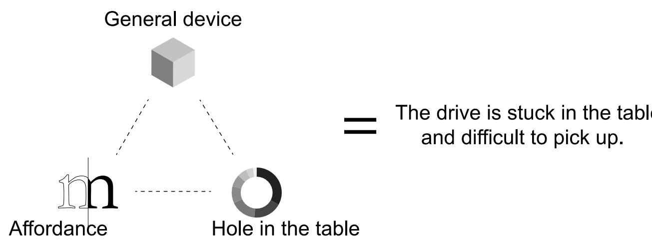

Figure 11. Model resulting in interpretation: the drive is stuck in the table and will be difficult to pick up.

A final example: in the *float* experiments, when the USB drive was seen as a container of data, the augmentation interpreted as the drive floating, and the meaning interpreted through the category of notification, one participant thought that the drive floated as a notification to the user that it held the data the user required at that moment (Figure 12).

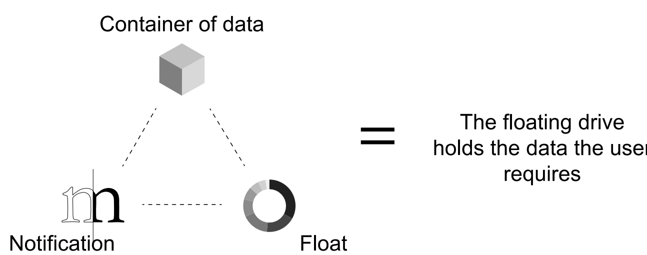

Figure 12. Model resulting in interpretation: the drive is floating to notify that it holds the data required.

DESIGN RECOMMENDATIONS

Inability to interpret meaning from augmentation experiments in this research can be explained as the failure to draw a connection between two or more points in the experiential augmentation model. The following section uses observations from the experiments to provide design recommendations for better execution of Experiential Augmentation.

Use understandable execution:
The USB sinking augmentation was sometimes interpreted as the drive sitting in a hole in the table because of insufficient specificity in execution.

Make the augmentation a little unusual:
If augmentations could logically appear in reality, viewers may interpret them *as* reality, and not realize they are an augmentation with underlying meaning. For example, the discount card losing color was sometimes interpreted as a card that just happened to be printed in black and white.

Make sure augmentations do not conflict with schemas of the object:
In the example that played the sound of water flowing over a USB drive being plugged into a computer, participants mentioned they did not like their electronics near water, and the sound made them uncomfortable. Thus, the sound should have been changed to one more reminiscent of data.

When appropriate, use augmentations that have a slightly negative meaning:
Participants often saw augmentations that have 'positive' meaning, such as floating upward as a call for attention, and defaulted to interpreting the augmentation as a simple notification rather than finding a deeper metaphorical connection. Negatively connoted augmentations, such as sinking did not have this problem. Thus, when deeper metaphorical interpretations are needed, negatively connoted augmentations have a higher chance to be successful.

Check for completeness
Extrapolate the augmentation/meaning combination to its extremes to ensure they work. In the USB floating example, participants were told at the end of the experiment that the intention was to depict a drive that was light because it was not carrying much data. They then questioned what would happen if the drive was completely empty: would it float upward to infinity?

PROCESS REFLECTION

Culture
The survey was taken by people from various cultures and ages. However, the anonymous nature of the survey precluded any conclusions that could be drawn from these two variables. Some responses in the survey, especially those relating to the understanding of money and pop culture, could be both culturally and generationally specific. For future iterations of testing, more information should be gathered on the backgrounds of participants to control for age and cultural differences, and a more intentional sampling method could be used.

Scenario and context
We purposefully did not place our objects in a specific context, in an attempt to keep the context from influencing the meaning of the visualizations for the participants. This allowed participants to create their own context around the objects. For example, sometimes they imagined a business card was received after a recent business meeting, and a loss of rigidity was an indicator of the trustworthiness of the giver. Other times the card was received further in the past, and the rigidity loss signed the card's information had become invalid. Without giving participants a specific context, they were free to imagine a range of identities for the object. However, when doing future testing of experiential augmentations designed for a specific object and purpose, it may be useful to situate the test in a specific context and scenario in order to focus participants on specific object/augmentation interpretations.

FUTURE WORK
This research began with a framing of experiential augmentation, which is the use of experiential and qualitative augmentations to augment real world objects, in the future context of ubiquitous computing. We have created a model that helps designers break down a viewer's interpretation of Experiential Augmentations, which can become a tool for iterating augmentations to target specific interpretations.

This model is at the moment only useful when the designer already has results from testing of an augmentation. We hope in the future to develop tools to aid the initial ideation of experiential augmentations.

Furthermore we are beginning implementation of qualitative augmentations to objects using consumer AR platforms such as ARKit and ARCore.

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