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EMPLOYING DESIGN REPRESENTATIONS FOR USER-FEEDBACK IN THE PRODUCT DESIGN LIFECYCLE

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Abstract

The product design lifecycle is dependent on user-feedback to deploy products with the highest rate of market success. User-feedback informs a product design to cater to the needs of the consumer. Feedback can come at any stage of the design lifecycle but earlier feedback leads to more significant impact in design decisions/direction. This study seeks to make use of design representations – like sketches – to represent a real product and consequently elicit early feedback. In this study, 5 different design representations of a heater product were created and validated for the purpose of exploring their capabilities. 36 feedback-sessions were conducted to gather data on the representations and this data was coded to distill the feedback and discover the representation's shortcomings compared to the real product. The results informed a plan to update the representations to more accurately represent the real product. The trends observed while coding shed light on common oversights made by designers in creating representations of a concept product - this will contribute to developing a system for producing design representations optimal for acquiring feedback in the design-lifecycle.

Keywords: Design process, New product development, Early design phases, Design representation, Augmented reality

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1 INTRODUCTION

An important factor in the success of new products is gaining an understanding of user needs and wants and integrating them into the New Product Design (NPD) process. Many methods are utilized to identify these needs. Often they involve gathering opinions and input on a product based on some representation of a product concept. The general understanding is that the more realistic the product representation the better the input that can be elicited from a user. The goal of this study is to test this assumption by comparing user evaluations of various types of design representations with evaluations of actual products on which they are based.

During the NPD process, it is common for designers to feel that they do not have enough information about users' needs (Bruseberg and McDonagh-Philip, 2002). This is especially true at the front end of the design process (Moultrie et al., 2007) when many different ideas for a product are considered. Gathering this information is strongly linked to product success, but the best way to collect this information and which components of it will be most useful is not currently well defined (Creusen, 2011).

The need to understand what information from users will be most useful is not confined to the very beginning of product development. The use of detailed physical prototypes is often recommended to gather detailed input, particularly for subjective attributes such as aesthetics and emotional appeal, ergonomics and usability, product integrity or craftsmanship (Srinivasan et al., 1997). The main drawback with these types of prototypes is that they cannot be built unless the product's design concept is already very well defined. This means that they are only available later in the process or after major design decisions have been made. Creating these highly detailed models can be time consuming and expensive. Even with rapid prototyping techniques, constructing a detailed model for every design permutation that might be considered is not feasible.

The dilemma for a product designer is that one of the most useful times for input is during the early stages of concept development. Better initial understanding of needs and preferences allows good concepts - to be generated and selected - more quickly leading to fewer dead ends, fewer design iterations, and fewer design defects. Design defects generally become more time consuming and costly to fix the later in the design process that they are identified (McGrath et al., 1992).

Since constructing a highly detailed model of early concepts is not feasible, designers will utilize other types of design representations such as sketches, storyboards or digital renderings. Unfortunately users are not very good at accurately visualizing a product from an abstract concept (Leonard-Barton, 1992). These types of design artifacts leave much more to the imagination. The more abstract or unfamiliar a concept is to a user, the less likely they will be able to provide an accurate opinion of it.

The goal of this paper is to identify attributes of design representations which are commonly misunderstood/misinterpreted by end users. The eventual aim is to develop guidelines for creating representations that more accurately convey design and engineering attributes to end users so that more reliable input can be solicited earlier in the product development process. In particular, this paper will investigate commonly used representations of concept sketches, 3D renderings, storyboards and appearance models.

The design representations were chosen to match those that are commonly used during the design process and which may be utilized in order to inform design decisions. Storyboards may be used throughout the design process but are very common in the early stages. Their purpose is to communicate different designs and ideas to users and other stakeholders in a common visual format that can be clearly understood by a wide variety of people (van der Lelie, 2006). Concept sketches are another form of visual communication. They are used to provide a specific and detailed view of a particular design idea and product form. They are almost always created by designers as part of the design development (Bloch, 1995). 3D renderings are electronic representations of a design idea. 3D renderings allow a design concept to be viewed in detail from any angle or perspective (as opposed to a static sketch). They can be rendered such that they look realistic, as the final product would, giving a user a very accurate impression of what a product will look like. 3D renderings are also almost always created as a design is modeled in preparation for manufacture. These models can be used to do things such as show the product within a natural environment, demonstrate usage and even perform ergonomic evaluations (Kuo and Chu, 2005). Appearance models (AP models) are created to evaluate the intended form of a design concept (Evans, 2002). They are constructed so that they have the exact same look, feel, materials and other attributes that the final produced product will have. They are non-functional but are the same in every other way. The actual products will be representative of a production product that is finally created from a representation.

In addition, augmented reality (AR) design representations will be examined in order to compare them with the other types. AR refers to a view of real or physical world in which certain elements of the environment are computer generated. These virtual elements could be a modification of a current element in the real world or could be an entirely new element and is superimposed over the real world view. (Azuma, 1997) This technology is beginning to see some use in a variety of industries including product development and healthcare, so it is important to begin to understand the impact of this technology in these contexts.

2 METHOD

This study was the first, exploratory step in investigating how AR representations are different (or similar) to other kinds of (more common) concept representations - used in the design lifecycle to communicate product concepts to users. For this study; sketches (Figure 1), 3D renderings (Figure 2), storyboards (Figure 3), appearance models (Figure 4) and AR models (Figure 5) of an existing product, a Sunbeam Heater – Model SFH5264MW (Figure 6) were created. The first 4 representation types mentioned above (Figures 1-4) were chosen as they are commonly generated and utilized during the normal product development process. The goal was to represent the real product as accurately as possible within the medium of each kind of representation. Rhinoceros 5 was used to create the 3D Renderings as well as the models used for AR. The Vuforia application running on an Apple iPad was used to present the AR models to study participants.

A total of 36 undergraduate volunteers (15 male and 23 female) were recruited to evaluate the product representations. The evaluation consisted of comparing the assigned representation side by side with the actual product. The goal was for the participants to identify any detail about the representation that they felt did not accurately represent the product.

While evaluating the representations, each participant completed the USE Questionnaire (Lund, 2001). The purpose of this was twofold. One of the most commonly used methods for evaluating a product is through usability evaluation. The USE Questionnaire provides an existing instrument with well-defined constructs of ease of use, satisfaction, learnability and effectiveness. While participants in this study were not actually performing a formal usability evaluation, the goal was to have each participant consider the accuracy of the design representation within the context of each survey question. This provides more assurance that each evaluation will consistently consider all of the same aspects of the product.

Participants were instructed to describe aloud any part of the design representation they felt was not accurate based on the survey question. Answers were transcribed and evaluated through a qualitative data analysis method known as initial coding (Saldana, 2009). A code in qualitative inquiry is a word or phrase that encapsulates the meaning of a statement provided by a subject.

All codes were defined based directly on participant comments that were transcribed during the evaluation sessions. The need for representing the meaning of things said by subjects in a consistent and non-biased way, so that information could be compared and analyzed, led to the initial coding approach which involved line-by-line coding of the transcript data. Also, post the first coding cycle an approach of defining categories, (ex: misrepresentation) to link codes across the different representations was employed (Charmaz, 2006).

In a second run through the coding cycle, the codes were further refined and mapped for recurrence in each session and over-all sessions. Finally, an analytical memo that documented the most relevant differences to refine in the representations was drafted from the coding findings. The memo was a theorizing write-up of the ideas about the codes and the patterns observed in their trends. It contained the apparent trends observed from the coding and added to it the conceptual elaboration and researcher's own position post conducting the data collection sessions (Glaser, 1978).

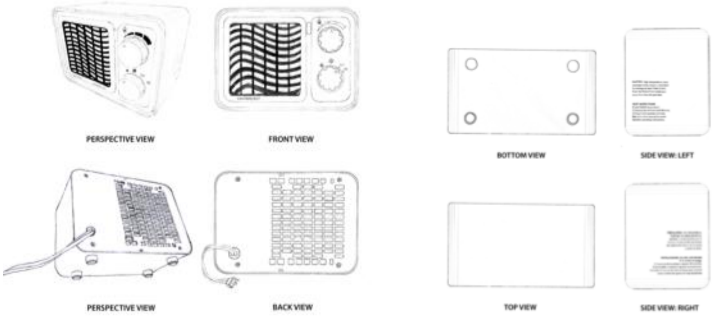

Figure 1. Sketch Representation

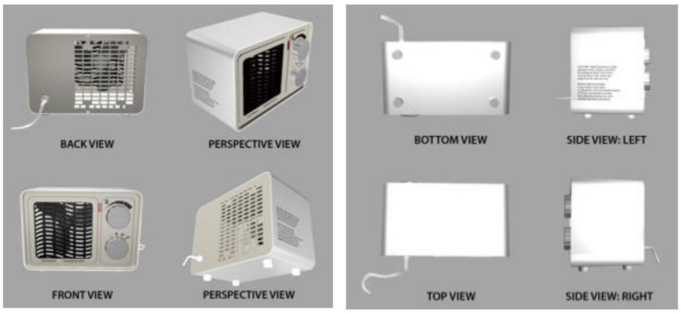

Figure 2. 3D Render Representation

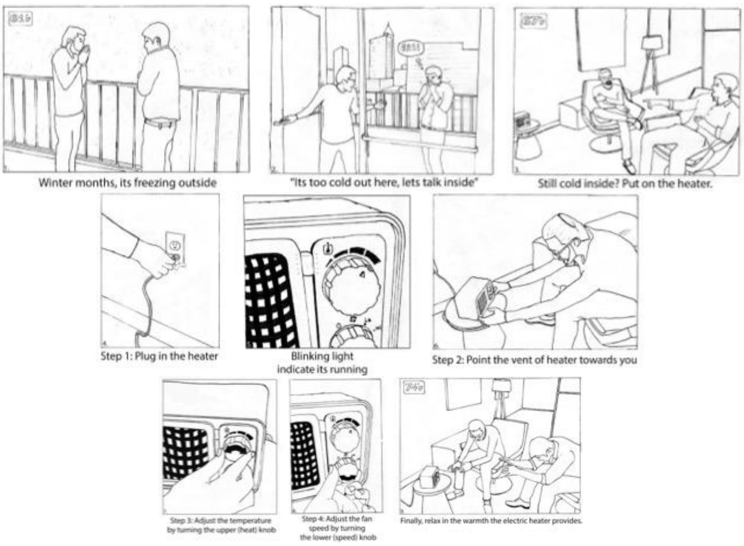

Figure 3. Storyboard Representation

Figure 4. Appearance Model Representation (from left to right, a. Front View b. Bottom view c. Perspective View - Right d. Perspective View - Left)

Figure 5. Augmented Reality Representation (left to right, a. AR Image Target b. AR model via iPad screenshot)

Figure 6. The Sunbeam Heater SFH5264MW (from left to right, a. Front View b. Bottom View c. Perspective View - Right d. Perspective View - Left)

3 RESULTS

The coding cycles lead to the distillation of feedback collected from the validation process of the representations. A total of 31 distinct qualitative codes were defined - spanning over the unbiased analysis of all five representations.

The codes were designated into two broad categories in analyzing differences between the representations and the real product:

1. **Misrepresentation** – This category defined an aspect of the representation where an attempt to match the real product had failed or was erroneous. 14 codes were associated with this category.
2. **Under-Representation** – This category defined properties or attributes of the real product that were simply missing or had been overlooked while producing the representation. 12 codes were associated with this category.

The categorizing for 26 of the codes was designated using the aforementioned categories with no overlap. The remaining 5 codes were uncategorized. Following the categorization, the codes were further analyzed by observing trends in the data collected. The primary focus was on the frequency of the appearance of any code specific to a certain design representation – as shown in Tables 1-5.

3.1 Sketch Representation Analysis

Table 1. Sketch Representation – First Cycle Initial Coding

Code Relevance Hierarchy	Code Frequency	Code Description	Additional Details
code4	6	Scale: Misrepresentation	50% of volunteers felt sketch was bigger, 33.3 % felt scale was off, 16.67% felt scale was small
code7	3	Light: Under-Representation	66.67% of sketch's responders were female
code2	2	Missing Sticker: Under-Representation	50% of overall came from sketch representation
code3	2	Cord Length Short: Under-Representation	50% of overall come from sketch representation
code9	2	Dial Motion: Misrepresentation	50% of representation response believed top dial clicks and vice versa
code13	2	Feedback Gap: Under-Representation	No noise feedback

There was a common confusion among study volunteers that the scale of the product displayed by the sketch representation was not identical to the real product's dimensions. However, there were opinions of it being bigger, smaller and also 'just off' in terms of scale. Another major point of discrepancy was the red light component in the sketch representation being under-representative of its purpose and functionality. Most users felt they couldn't discern said component from the sketches to be the light until they compared with the real product.

Some of the relatively representation-specific feedback on the sketch representation was

- Missing the product attributes sticker label from the back view.
- Misrepresentation of the product's cord length to be much shorter than the real product’s cord.

Some of the more generic feedback that the sketch representation elicited was

- The different dial motions for the top and bottom control dials was not represented.
- Feedback from the product - like noise during runtime - was not represented.

3.2 Render Representation Analysis

Table 2. 3D Render Representation – First Cycle Initial Coding

Code Relevance Hierarchy	Code Frequency	Code Description	Additional Details
code17	5	Dial Pointer: Under-Representation	Dial’s pointer missing apparent only in renders
code4	4	Scale: Misrepresentation	Only 50% off total render volunteers thrown off by scale; 50% scale bigger and 50% ‘off’ opinion
code18	3	Fan graphic: Misrepresentation	Graphic confusion only apparent in 3D render
code7	2	Light: Under-Representation	Unrealistic red light component in 3D render
code11	2	Fan: Under-Representation	Smaller and thinner fan
code12	2	Missing Spanish: Under-Representation	66% of overall response came from 3D render
code15	2	Colour/Texture Mismatch	Metallic difference in textures
code19	1	Support Arm: Under-Representation	50% of overall response came from 3D renders

There was a common point of confusion among study volunteers in discerning the pointers on the two control dials in the 3D render representation. This threw off the study volunteers in judging the usability of the concept product from the representation as well. There was also a major confusion in analyzing the graphic of the lower control dial - specifically the fan symbol as it appeared to many study volunteers as a solid black circle. Apparent under-representations also pointed out were the missing Spanish instructions from the left view of the render representation, the missing support arms from the interior of the rendered product and the fan component seeming smaller and thinner in blade width than the real product's fan. Some edge case users also discerned differences in the colors of the render representation, which informed them of more metallic materials as opposed to the real product, which is completely plastic in construction. Interestingly, only one edge case user pointed out the aforementioned missing support arms.

The relatively representation-specific feedback on the 3D render representation was

- Missing dial pointers.
- The fan symbol graphic appearing to be a solid black circle.
- Missing Spanish instructions.

Some of the more generic feedback that the 3D render representation elicited was

- The red light component appearing to be less aesthetic compared to the real product's red light.
- Scale confusion.

3.3 Appearance Model Analysis

Table 3. Appearance Model Representation – First Cycle Initial Coding

Code Relevance Hierarchy	Code Frequency	Code Description	Additional Details
code 15	5	Dials' mismatch	83% of AP Model's responders thought there was a texture/colour misrepresentation; 40% of discrepancy was observed in dials alone
code25	5	Dial Sturdiness: Misrepresentation	83% felt their reliability judgment was affected
code 9	4	Dial Motion: Misrepresentation	75% felt lower dial is smooth, no audible click
code26	3	Labels' Edge (AP): Misrepresentation	Only apparent in AP Model
code28	1	Caution Label size: Misrepresentation	100% of overall responses came from AP Model

There was a common point of confusion from study volunteers when viewing the dials of the Appearance Model (AP model) representation. Specifically, a) the texture of the dials' finishing (i.e. bumps on its surface) and, b) the looseness of its attachment to the main body of the AP model (resulting in occasional detachment). Most of the users were happy with the color accuracy of the representation to the real product with some edge case reviewers even pointing out that the AP model looked 'cleaner' than the real. The other components that the study participants felt were under-represented were a) the AP model's fan seemed to be a bit smaller in terms of width of the blades and, b) the heating coils, which were not included in the AP model. Some users claimed that looking at the real product, the sight of the heating coils inside made them believe it was a heater immediately whereas the AP model posed an ambiguity in terms of obvious product purpose and functionality.

The representation-specific feedback on the AP model representation was

- The dials' looseness seemed to make the product less reliable.
- The model's labels appearing explicitly to be stickers in the AP model. (edges of the stickers were visible)

Some of the more generic feedback that the AP model representation elicited was

- Confusion over the specific sizing of the labels and font sizing (one edge case user discerned the Caution label to be of smaller font in the representation).
- The dials not clicking on rotational movement identically to the real product's dials (noise feedback gap).
- Most users were satisfied by the scale, weight and commented that at a brief glance the AP model representation and the real product looked identical.

3.4 Storyboard Representation Analysis

Table 4. Storyboard Representation – First Cycle Initial Coding

Code Relevance Hierarchy	Code Frequency	Code Description	Additional Details
code23	5	Capability 2 people: Misrepresentation	71% of overall response from storyboard
code1	3	Too many panels: Over-Representation	60% of overall response
code20	3	Product usage need: Misrepresentation	100% of overall response from storyboard
code21	3	Blinking Light function: Misrepresentation	100% of overall response from storyboard
code9	2	Dial Motion: Misrepresentation	Thick arrow confusion only from storyboard

There was a common point of disbelief from study volunteers with regards to the storyboard panel #9 - which represented the heater product providing functionality for more than 1 individual. An edge case volunteer argued that the storyboard characters huddling close to the product in panel #9 reinforced that opinion. The storyboard representation elicited this reaction more than any other representation. The second common opinion among study volunteers was that the storyboard employed too many panels to display the product's functionality and usage. The number of panels (9) intuitively made a volunteer believe think there were 9 steps of usage but in fact the real product had only about 4 steps.

Some of the exclusive feedback that the storyboard representation elicited was

- Panel #3 representing a low need for the usage of the product - volunteers believed that the characters already looked comfortable without the use of the heater and only used it as an afterthought which made them (the study volunteers) believe it was not an effective product.
- Panel #5 misrepresented the function of the red light as blinking - when it is only supposed to light up.
- The representation of the dial's motion was marred by the usage of a thick arrow for each dial - the thickness of the arrow seemed to imply heavy force to manipulate the dials and the same arrow being used for both dials implied identical motion for each dial - which was not representative of the real product's smooth top dial & clicking bottom dial.

Some of the more generic feedback that the storyboard representation elicited was

- Under-representation of the range of the temperature dial being beyond the temperature bar graphic.
- No representation of the noise that the product produced at runtime.
- General appreciation among the volunteers for the explicit instructions and usage information - in the form of panel labels - which was exclusive to the storyboard representation (there were no instructions or descriptive wording in any of the other design representations used in the study).

3.5 Augmented Reality Model Representation Analysis

Table 5. Augmented Reality Model Representation – First Cycle Initial Coding

Code Relevance Hierarchy	Code Frequency	Code Description	Additional Details
code15	5	Dials Mismatch	Materials differed widely as well as colours and lighting condition
code9	5	Dial Motion: Misrepresentation	Temperature dial motion smooth not apparent
code4	4	Scale: Misrepresentation	Zooming bias
code27	3	Bottom View: Under-Representation	100% of overall response from AR
code29	2	Lighting Difference: Misrepresentation	100% of overall response from AR
code30	2	Render Flicker: Misrepresentation	100% of overall response from AR
code24	1	Rubber-Bottoms: Under-Representation	50% of overall come from AR
code31	1	Font/Symbol Size: Misrepresentation	100% of overall response from AR

There was a common belief among study volunteers that the augmented reality experience offered an accurate representation of the real product in terms of appearance and real world space i.e. scale. However, there was some opinion on there being a mismatch between the control dials - specifically the colors being matte as compared to the shiny control dials on the real. There was also a bias in terms of the ability to zoom in on the augmented reality representation - study volunteers found it difficult to readjust to the original scale. In comparison to the real product the augmented reality model also elicited much feedback on the realization that the two dials did not have the same motion – top dial was smooth rotation and the bottom dial clicks - which users figured out through the use of the real product. The study volunteers felt the representation would be more effective if this kind of interactive information could be discerned.

The representation-specific feedback on the augmented reality representation was

- Bottom view of product is inaccessible and indiscernible.
- The lighting i.e. viewing scenario of the augmented reality experience seemed very different from the lighting that the real product was subject to i.e. the lighting of the room that the validation study was conducted in.
- The augmented reality model flickering had a negative effect on aesthetic judgement.
- The rubber bottoms that supported the real product were not distinguishable from the representation (since the bottom view was not accessible).
- An edge case opinion - the sizing of the graphics and the fonts of the labels on the representation product were different from the sizes on the real product – namely the 'Lo', Hi' & 'CAUTION' labels and the fan graphic and temperature dial bar graphic.

4 DISCUSSION

The sketch representation was the most minimalist representation in terms of functionality, usage, colour and texture. Most of the study volunteers tried to discern scale information from this representation first and that was the biggest point of displeasure. The ambiguity of the red light component was perhaps unavoidable in this kind of representation but edge case users felt a callout with a label could help.
The most relevant factors to act on for iteration two of the sketch representation were

1. Precisely matching the scale for each orthographic sketch to the real product.
2. Representing the product attributes sticker on the back view.
3. Representing the power cord length to be identical to that of the real product.
4. Perhaps adding callouts to the sketch to improve the informative attributes of this representation.

The 3D render representation offered an additional layer of information to the sketch representations in the form of colour and materiality suggestion. This seemed to be the focus of the study volunteers as well, which made the missing pointers and fan graphic misrepresentation the focus of the discussion, aside from the scale issues, which had been the primary pain point in the sketch representation. Many study volunteers pointed out that the colours of the representation were not completely identical to the real product - which was due to the lighting options selected during the rendering.
The most relevant factors to act on for iteration two of the 3D representation render were

1. Render pointers on the control dials to be more apparent.
2. Correcting appearance of the fan graphic symbol, located above the lower dial.
3. Precisely matching the scale for each orthographic render to the real product.
4. Precisely applying digital colours and rendering options to match appearance of the real product.
5. Redesigning fan component to have wider blades identical to the form of the real product's fan.
6. Adding Spanish instructions to the side view of 3D render.

The AP Model elicited very relevant feedback from a perspective of product interaction. Perhaps because the scale of the model and the real product was so seemingly similar in this scenario, the study volunteers simply tended to accept it and look at other aspects of the model more closely.
The most relevant factors that seemed to require adjustment, for iteration two of the AP model were

1. Refining the appearance and texture of the dials (smoother surface).
2. Improving the mechanical housing of the dials in the main body of the heater (for a tighter fit).
3. Redesigning fan component to have wider blades identical to the form of the real product's fan.
4. Incorporating coils into the interior of the model.
5. Refining the labels to be less discernible as stickers on the model.

The storyboard elicited feedback that was very specific to the usage and task flow of the product. Since there were only two controls with obvious functionality, study volunteers tended to focus on user interaction with them. Some edge case users also commented on the story’s theme - mainly that the indoor environment from panel #3 onwards seemed already comfortable enough without the heater.
The most relevant factors to act on for iteration two of the storyboard representation were

1. Representing accurately the distinct styles of motion of the two control dials with informative arrow graphics.
2. Distilling the total number of storyboard panels to simplify the perception of number of steps involved in the usage of the product.
3. Copy update for panel #5 to correct the ‘blinking light’ description.
4. Thematic update to panels #1-3 to solidify need for the product in the character's scenario.

The augmented reality (AR) representation offered users a unique experience in terms of viewing a concept product in real space with its intended design language. The study volunteers reacted favourably to the technology and AR model however a common perception was that this form of advanced technology should be able to offer interaction information as well – which could be discerned from the less technologically advanced, AP model. A unique challenge that arose in the study scenario was the lighting of the study room having a noticeably different effect on the real product than the virtual lighting that the AR model was subject to. Most of the users quickly picked up interacting with the model and did not give much relevance to the flickering of the AR model - considering it a compromise for the medium. Users however did comment that the image target for the AR experience prevented them from getting the bottom view of the product.
The most relevant factors to act on for iteration two of the AR model were

1. Match virtual lighting when creating the AR representation to the lighting of the study location.

2. Improve technology implementation to allow for bottom view display.
3. Precisely applying digital colours/textures to more accurately match appearance of the real product.

5 CONCLUSION

The study outcome painted the AR experience in a favourable light with most users expecting even greater levels of interaction from the AR heater representation, at a level that could match the interaction and dynamic feedback that was clear in the AP model – specifically, the control dial's rotation and possibly the fan spinning. The AR heater model was more of a 3D rendering attached to a marker but a more realistic representation should be interactive in a way that displays the product's functionality.

With technology improvements, adding simple interactions to AR applications can deliver more dynamic information to users without the intense replication process and craftsmanship that goes into making AP models **-** or the other types of representations that were used in the study.

As an exploration of the product representation capabilities of augmented reality, this study prompted a question of how interactive AR applications can be designed with user interfaces that are suggestive of the design intent of the real product. Users were more than capable of using the iPad as a viewfinder to access the different perspective views of the AR representation. However, what kinds of interface designs can accurately communicate real world interactions, such as representing the rotation of a physical knob on a touch screen? Control panels tend to incorporate interfaces like buttons, dials, sliders etc. Studies could delve into translating these physical elements into AR interactions, with variances in on-screen tapping, finger pressure etc. or – as AR headwear becomes common – eye movements, that can communicate the intended real world interaction of the concept product being designed.

AR models face technology and user interface challenges but are a ripe opportunity for studies to explore their potential role in the design lifecycle, especially as AR technology grows more ubiquitous.

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