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DOES PROTOTYPE FORMAT INFLUENCE STAKEHOLDER DESIGN INPUT?

Deininger, Michael (1); Daly, Shanna (1); Sienko, Kathleen (1); Lee, Jennifer (1); Obed, Samuel (2); Effah Kaufmann, Elsie (2)
1: University of Michigan, United States of America; 2: University of Ghana, Ghana

Abstract
This research investigates how prototype format, here defined as the physical nature of a prototype, influences feedback from stakeholders in the process of designing a medical device. We presented medical practitioners with a variety of prototypes, including a sketch, a cardboard mock-up, a CAD model and a 3D printed model, of the same idea for an assistive, contraceptive implant insertion device and asked for their feedback. We found that the prototype format influenced the distribution within the answer categories. We also found that the type of question influenced the distribution within the answer categories.

Keywords: Design practice, New product development, User centred design, Prototypes, Stakeholders

Contact:
Michael Deininger
University of Michigan
Design Science
United States of America
midei@umich.edu

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1 INTRODUCTION

Designers often use prototypes to communicate their ideas to others. The format and level of refinement of these prototypes frequently depends on the stage a project is in and can include conceptual sketches, primitive mock-ups and CAD models as well as refined 3D printed models that are virtually indistinguishable from a production part. Various factors such as material, finish, fidelity, and the visual appearance of a prototype, may influence how stakeholders perceive ideas. And while these factors do not always reflect the intended quality or functionality of the final product, they can influence the judgments of stakeholders and users when responding to a new idea (Crilly et al., 2004). Additionally, stakeholders might have different levels of experience with the product domain they are asked to comment and provide feedback on, and their motivation and investment in the project influences the design feedback they provide (Chamorro-Koc et al., 2009). Not all stakeholders can look beyond "not ideal" prototypes and as a result, stakeholders might perceive good ideas negatively because of a less favorable presentation and not-so-good ideas more positively due to a more refined form of presentation (Sauer and Sonderegger, 2009; Seva and Helander, 2009). It is therefore critical that designers select a form and quality of presentation that is appropriate for the targeted stakeholder group as well as the design question(s) asked when soliciting feedback and input on a concept or idea.

Prior research has shown that the quality of sketches (Kudrowitz et al., 2012; Macomber and Yang, 2011) as well as physical models (Sauer and Sonderegger, 2009; Sonderegger and Sauer, 2010) do indeed influence the perception of an idea, however, these studies were often limited to a single prototype format as well as a particular stakeholder or user group. This study sought to build on the aforementioned research and aimed to broaden the findings by looking across various prototype formats, which are defined here as sketches, mock-ups, CAD models and 3D printed models. The study also looked across different stakeholder groups, here nurses/midwifes, medical students and medical doctors, who were introduced to an assistive medical device. This study presents a subset of the feedback these stakeholders provided and describes how different prototype formats influenced their answers, as well as how feedback differed across the individual stakeholder groups.

2 BACKGROUND

Prototypes have a positive influence on design outcomes. For example, Dow et al. found that parallel prototyping leads to better and more diverse design outcomes (Dow et al., 2010), Schütze et al. established that simple prototypes like sketches lead to better design outcomes (Schütze et al., 2003), and Yang and Epstein found that prototypes with fewer parts correlate with better design outcomes (Yang and Epstein, 2005). A large body of research supports this positive influence prototypes have on design outcomes and a number of studies have shown that designers use a variety of prototypes during various stages of a design project. Hilton (Hilton et al., 2015) found that, instead of working on a complete system, expert designers often iterated at the component level, and Houde (Houde and Hill, 1997) developed a tool to help designers with the strategic use of prototypes based on industry practice. While most studies focused on the influence that prototypes have on the designer, the design process, or the design outcome, few studies have investigated the influence of prototypes on stakeholders. These stakeholder-focused studies have found that past experiences of stakeholders, and the domain knowledge stakeholders have about the product they are expected to provide feedback on, are interrelated. It is therefore critical that stakeholders who are evaluating a new device, are familiar with, and possess background knowledge about the proposed device and its intended use (Chamorro-Koc et al., 2009).

In addition to domain knowledge and experience of stakeholders, the quality of prototypes also affects the feedback stakeholders provide. For example, Macomber and Yang investigated how sketch quality influenced stakeholder feedback and found that realistic and clean sketches were ranked higher than rough sketches (Macomber and Yang, 2011). Similarly, a study by Kudrowitz et al. found that sketch quality was directly correlated with how stakeholders perceived and ranked the creativity of an idea (Kudrowitz et al., 2012).

Studies that asked participants to perform tasks on simulated mobile phones found that aesthetics played a mayor role in how stakeholders rated the functionality of a design (Sauer and Sonderegger, 2009; Sonderegger and Sauer, 2010). This echoes a study by Tractinsky et al. that found that favorable aesthetics can overrule participants' perceptions of functionality of automated teller machines (ATMs) (Tractinsky et al., 2000).

However, a study by Reid et al. found that in some cases, the quality of the product representation did not influence participants' preferences, while in other cases, it did (Reid et al., 2013). This suggests that researchers should be cognizant of the form of representation and that multiple forms of representations might be necessary for robust results.

These inconsistencies, combined with the fact that many of the current studies on prototypes and stakeholders 1) often utilize only a single prototype format like sketches or computer interfaces (Walker et al., 2016), 2) are frequently limited to a particular stakeholder group, and 3) use surveys, eliminating the opportunity for multiple stakeholder groups to review a variety of prototype formats, warrant further investigation into how prototype format influences the design input stakeholders provide.

3 METHODS

In this study, three groups of healthcare practitioners (nurses/midwifes, medical students, medical doctors) were introduced to prototypes of an assistive, long-term contraceptive implant insertion device (Mohedas et al., 2015). The prototype formats consisted of a sketch, a cardboard mock-up, a CAD model and a 3D printed model. Two rounds of interviews were conducted so that all participants could be presented with two prototype formats, but the results presented here focus on the first presentation only. Data were collected through semi-structured interviews and three representative interview questions were selected from a set of nine questions that were determined essential in collecting actionable feedback from stakeholders for this analysis. These questions focused on stakeholders' opinions on the viability of the device, what changes the stakeholders would suggest making to the device, and how stakeholders thought patients would feel about the device being used during an implant placement procedure, the latter asking participants to comment on the device from another person's perspective.

3.1 Participants

The 45 participants in this study were healthcare practitioners from a hospital in Ghana. They included 18 nurses or midwives, 10 medical students and 17 medical doctors. These participants were chosen because they represented a cross section of the target user group for the proposed device, and would either be using it themselves, or advising and training others, in the use of the device. The participants were recruited through the family planning department of the hospital and received a small gift in appreciation for their participation. The research proposal was reviewed and exempt by a large, mid-western university's IRB and the head of the Department of Obstetrics and Gynecology, at the hospital in Ghana where the study took place.

3.2 Research Design

A qualitative research approach was chosen for this study that allowed for the exploration of the participants' impressions and interpretations of the device concept that was presented to them (Adams et al., 2011; Bucciarelli, 1988; Daly et al., 2013; Yilmaz and Seifert, 2011). A semi-structured interview protocol was developed to guide participants through the study and enabled the interviewer to ask follow-up questions and investigate details of responses more deeply (Creswell, 2013; Patton, 2014). The questions were specifically designed to elicit participants' impressions as well as to encourage them to critique or add to the proposed device concept. If a participant did not already provide an explanation of their answer, the interviewer asked "why" or "why not" they had chosen a particular answer.

Prior to starting the actual data collection, the research team developed and refined a number of research questions that led to the interview protocol. This protocol went through several revisions and iterations. Finally, the research team piloted the revised interview protocol with four participants (medical students from a university in the US) and finalized the protocol for the study.

A medical device intended to assist healthcare practitioners in resource-limited settings with the insertion of a long-term contraceptive implant was chosen for this study. The implant is supplied preloaded in a needle applicator and is currently inserted free hand into the subcutaneous tissue between the biceps and triceps of the patient. The proposed device is clipped to a blood-pressure cuff that is placed on the patient's upper arm and inflated, thereby pushing the tissue into a cavity at the bottom of the device. The device serves as a guide, positioning the needle at the correct insertion depth and reduces

the skill required for correct insertion. This allows lesser-trained healthcare providers like community healthcare workers to perform the procedure on a larger number of patients.
Four prototypes (Figure 1) were created to introduce the device to the study participants. All prototypes were created with the intent of representing what designers might create during the early design phases of a project, all conveying similar information regarding critical features of the device. The sketch and the CAD model were 2-dimensional representations that were shown in paper form (Sketch) or on a laptop screen (CAD model). The cardboard mock-up and the 3D printed model were physical objects that were handed to the participants for examination.

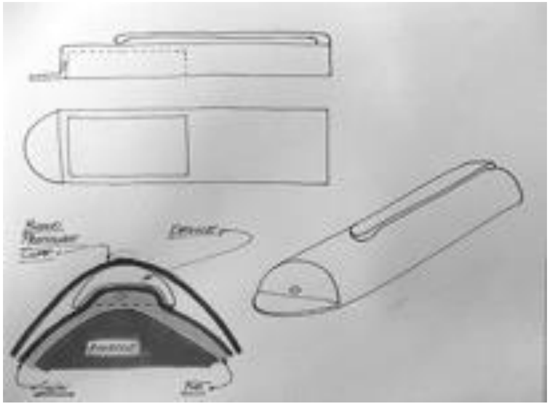
Sketch	**Cardboard Mock-Up**
	
CAD model	**3D printed model**
	

Figure 1. Prototype Formats

3.3 Data Collection

The data for this study were collected through in-person interviews at a family planning clinic at a teaching hospital in Ghana and all interviews were conducted during a one-week period. The participants were randomly assigned the type of prototype they reviewed according to their group membership (nurse/midwife, medical doctor or medical student). The interviews were conducted in English and audio recorded for later transcription.

3.4 Data Analysis

After transcription, two researchers read through the interviews and developed a set of criteria to determine the extent to which the information provided through the response was actionable, i.e. was the answer justified and/or offered additional design input that would allow a designer to apply information to the design of the device. From these criteria, the research team developed five coding categories and used Nvivo 10, a qualitative coding software, to identify answer categories that represented the types of responses stakeholders provided (Boyatzis, 1998; Creswell, 2013; Patton, 2014). Table 1 shows the answer categories that were developed and provides definitions as well as examples.

Table 1. Answer Categories

Category	Code	Definition	Example
I	Justified answer with additional design input	Provided input in addition to answering the question and justifying the answer	"So maybe it should be designed in (different) sizes"
II	Justified answer	Answered question affirmatively and provided justification	"I like, the ability of the device to isolate the skin and then the subcutaneous tissue from the muscle"
III	Unjustified answer	Answered question affirmatively but provided no justification	"Yes I think it will work”
IV	No answer, false-positive or circular logic	Provided no answer, answer was contradicting or made no sense	"I can't say" or “If you get it right, then it will work”
V	Missing Data	Question was not asked	N/A

4 FINDINGS

4.1 Do you think this concept will work?

The purposes of this question were to determine if the participants thought that the proposed device would solve the design problem and would function as intended by the designers. The findings are summarized in Figure 2 with respect to prototype type and stakeholder group and the highest and lowest occurring answer categories are discussed below.

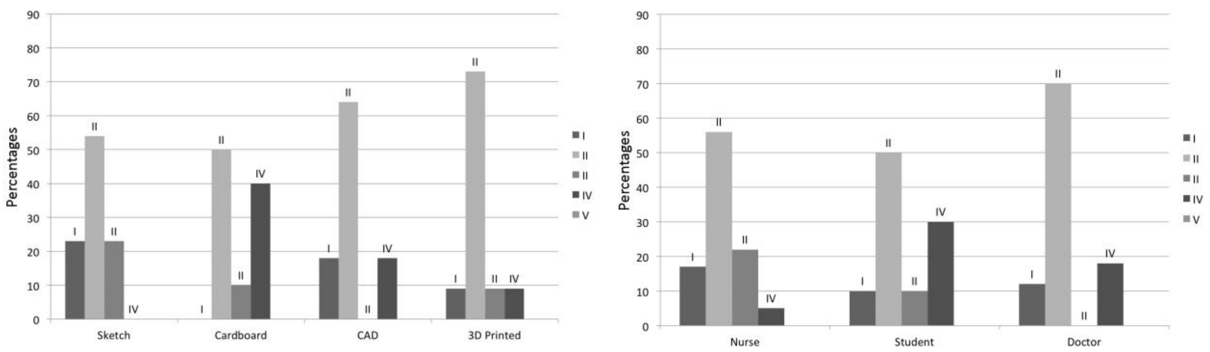


Figure 2. Responses to question: “Do you think this concept will work?”

The sketch prompted the highest percentage of justified answers with design input (Category I) for the question: “Do you think this concept will work?” For example, participant 40 voiced concerns about the precision of the device, indicating an area that might need to be addressed in the final design: “My only worry is if it will only get just skin into the cavity and not push any muscle into that space. But if it [is] designed such that it is only pinching the skin up into it, then I think it should be perfect.” Participant 25 added context-of-use concerns beyond the design of the device itself, mentioning that the willingness of the practitioners to adopt this device could be a critical factor: “Sure, if we want to use it, it will work.” In contrast, the sketch also prompted the highest percentage of unjustified answers (Category III) from the participants, for example, “It can work” (Participant 24).

The 3D printed prototype resulted in the highest percentage of justified answers with no design input (Category II). Participants developed a clear understanding of how the device would function and were able to justify their answers, as Participant 26 explained: “Oh it would. After it is placed on the skin of the patient and the cuff is inflated, the skin goes into this place and then… so it is left with the dermis, so in other words, when you insert the cannula, it keeps it within the sub-dermis, instead of getting into the muscles.” Similarly, Participant 39 explained: “It will work because you’ll release a portion of the skin where you want to insert into this area of the cavity, and so it will help you to gain access to your area you want to in effect, so I think it will work.”

The mock-up resulted in no justified answers with design input (Category I), the lowest percentage of justified answers (Category II), and the highest percentage of Category IV answers (false positive or circular logic), making it the least effective prototype. For example "I'm waiting to see. I can't tell. I mean it's new to me, like the whole idea about this, so I hope so." (Participant 35).
For this question, nurses provided the highest percentage of Category I answers, while doctors offered the highest percentage of justified answers (Category II). The lowest scores in those two categories were recorded for student participants.

4.2 How do you think patients will feel about this device?

This question had participants consider a patient's perspective when evaluating the device. In addition to discussing the function of the device, participants were asked to comment on how the device design might affect human aspects of the design such as perception, fear and comfort. The findings are summarized in Figure 3 with respect to prototype type and stakeholder group and the highest and lowest occurring answer categories are discussed below.

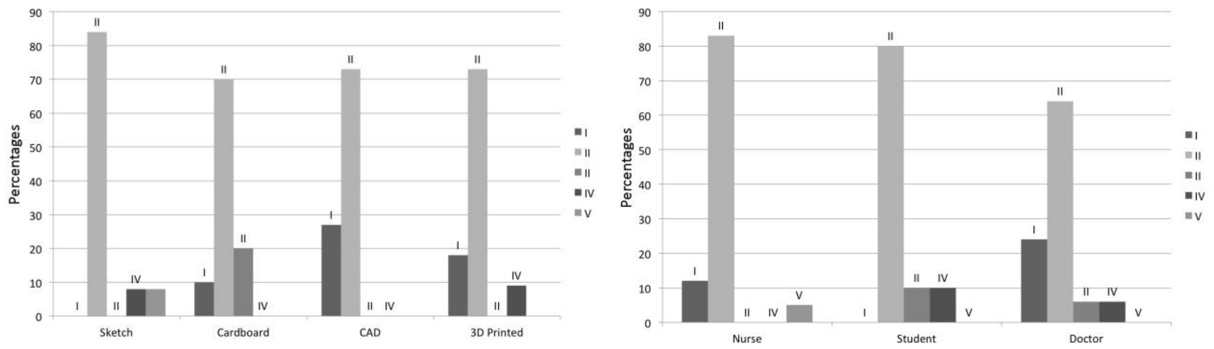


Figure 3. Responses to question: "How do you think patients will feel about this device?"

The CAD model prompted the highest percentage of justified answers with design input (Category I), followed by the 3D printed model and the mock-up. Participant 31 voiced concerns and commented on potential issues for thin patients: "Yes I think it will work, I guess… not for everybody, but if you end up having very thin people, someone very slim, the subcutaneous fat is like less to nothing. Then you might just be in some epidermis or something."
The Sketch resulted in no Category I answers, but the highest percentage of justified answers (Category II) for this prototype type. For example: "I think the patient will feel more relaxed. If there is an instrument to guide the insertion, I think the patient will feel more comfortable" (Participant 18). Participant 33 also explained how the device can help put the patient at ease: "Somehow it takes away the fear some people have with this, since this is attached to the cuff… maybe you are taking a blood pressure and you do it at the same time, so it will calm any anxiety there is."
For this question, doctors provided the highest percentage of category I answers, while nurses offered the highest percentage of justified answers. Students offered no Category I answers and had the lowest scores for Category II answers.

4.3 What would you change about this device?

This question prompted participants to articulate how they thought the design of the device could be further improved. This question went beyond critiquing the device and was asked last, allowing participants to summarize their thoughts. The findings are presented in Figure 4 with respect to prototype type and stakeholder group and the highest and lowest occurring answer categories are discussed below.

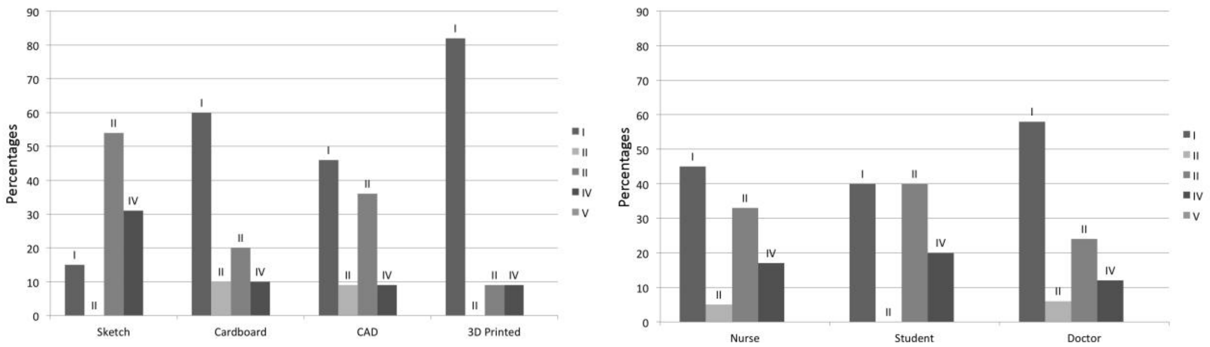


Figure 4. Responses to question: "What would you change about this device?"

The 3D printed model outperformed the other prototypes with the highest percentage of justified answers with design input (Category I) for this question. Recorded answers included "It's ok, maybe the size, just reduce it" (Participant 7), "I would love it if it had been [more] flexible than this" (Participant 16) and "Maybe the color, something… I think it should be attractive… maybe pink, blue" (Participant 26). The 3D printed prototype also resulted in the lowest percentage of unjustified and invalid answers, and included answers like: "I have no idea. I think you have to, you know, do testing on it before." Participant 42.

For this question, the physical models (Mock-up and 3D printed) resulted in higher percentages of justified answers with design input (Category I) than the 2-dimensional prototypes (Sketch and CAD model).

The sketch yielded the lowest percentage of justified answers with design input (Category I) and justified answers (Category II), and the highest percentage of unjustified and invalid answers (Categories III and IV) for this prototype type with this question. For example:" I think for now no because this is just on paper. I hope you understand me." (Participant 1) and "Well because I've not tried my hands on [it] or use[d] it before, I can't say anything about it." (Participant 25).

For this question, doctors provided the highest percentage of both Category I and Category II answers. Notably, this question resulted in the highest percentages of justified answers with design input (Category I) for all stakeholder groups.

5 DISCUSSION

5.1 Do you think this concept will work?

When asked if participants thought if the concept would work, sketches yielded the highest percentage of justified answers with design input (Category I). This finding might be explained by the fact that sketches are the least precise form of representation in this study and might leave the largest margin for interpretation and imagination for the stakeholders. Stakeholders might have thought that they saw something that wasn't actually there, or that things would be the way they imagined once the device would take on physical form (Tversky et al., 2003). Sketches were also the least finished or refined prototypes, a fact that might have empowered stakeholders to provide creative input because they thought it could easily be incorporated.

The fact that the cardboard mock-up yielded the lowest percentage of justified answer with design input could have been due to the physical properties of the model as well as experience of the stakeholders with critiquing prototypes. Several participants voiced concerns about cardboard not being an appropriate material for the device, even though they were told that the actual device would not be made out of cardboard (Tractinsky et al., 2000).

5.2 How do you think patients will feel about this device?

When asking participants how they thought a patient would feel about the device being used during the implant insertion procedure, the sketch resulted in the lowest percentage of justified answer with design input (Category I). The fact that some participants might have found it difficult to visualize how the device would interact with a patient might explain this. This likely was easier to do with a physical model, and several participants held the physical models against their own arm during the interview to get a feel for how the device would be applied.

However, the CAD model, even though also a non-physical prototype, yielded the highest percentage of justified answers with design input (Category I) for this question and outperformed both physical prototypes (Mock-up and 3D printed model). The CAD model was 3-dimensional in nature, but participants were not able to physically interact with the prototype or place it on an actual arm. A previous study by the investigators conducted with Ghanaian engineering students has shown that CAD models were frequently used during design, and the fact that stakeholders in this particular setting might be quite familiar with seeing virtual models could potentially explain this high score (Deininger et al., 2017). Similar to sketches, CAD models are non-physical models that might appear less finished than physical prototypes, which could give stakeholders the impression that there is still an opportunity to provide valuable design critique compared to reviewing an object that already appears fully designed.

5.3 What would you change about this device?

The question "What would you change about this device?" was asked last and prompted participants to provide input on the design. This, and the fact that participants had already thought about some of the pros and cons of the device, might explain the highest percentage of justified answers with design input (Category I) across all prototype formats for this question. The highest percentage of justified answers with design input (Category I) was recorded for the 3D printed model. For this question, this most refined prototype format enabled the highest percentage of stakeholders to be critical of the device and provide the designer with creative input (Reid et al., 2013).

The sketch resulted in the highest percentage of unjustified (Category III) and invalid answers (Category IV), highlighting that participants might have found it difficult to imagine how the device would be used in context. This in turn would have made it difficult for them to suggest measures to improve on the concept (Macomber and Yang, 2011).

Both physical models (Mock-up and 3D printed) scored higher than the virtual, 2-dimensional models. It is possible that the physical form might have made it easier for participants to be critical of properties that they didn't experience with the 2-dimensional models, such as size, texture or material properties.

5.4 General

When looking across the three questions presented here, not a single prototype format yielded the highest percentage of justified answers, with or without design input (Categories I and II). Instead, these percentages varied from question to question, and the high and low percentages of the last question are almost a reversal of the percentages of the first question. This finding echoes other studies that investigated prototyping strategies, choices, and the complexity of prototypes used (Camburn et al., 2013; Christie et al., 2012; Faas et al., 2014), and suggests that not one form of prototype can address all questions equally. Instead, a particular form of prototype might be better suited to address certain questions in a particular project domain (Reid et al., 2013).

Similarly, there is no clear indication that one particular stakeholder group provided more actionable feedback than another as the results varied across questions. However, in the three questions included in this study, nurses/midwifes and doctors outperformed students, which might be due to the fact that these two stakeholder groups had more experience with medical devices and procedures. This finding might indicate that more experienced stakeholders are preferable when designers seek feedback on a new device idea.

6 LIMITATIONS

There were several limitations to this study that could be addressed in future work. First, only a subset of the answers participants provided after they were introduced to the first prototype was presented. The analysis was also limited to descriptive statistics and future work should consider the feedback to all questions asked during the study as well as statistical analysis of the responses to explore if there were any significant differences between prototype types and/or stakeholder groups. Furthermore, the number of participants could be expanded and could include stakeholders from different backgrounds and geographical settings, as well as prototypes of non-medical devices, for more generalizable findings. A male researcher who was not a native of Ghana conducted all interviews, and all participants were non-native English speakers. These cultural factors might have influenced the richness of the participants' responses.

7 CONCLUSIONS

The findings show that the prototype format does indeed influence the quality of actionable feedback stakeholders provided, and that different stakeholder groups responded differently to different prototype types. Stakeholders with more experience in the domain provided more actionable feedback, and different prototype types corresponded with different degrees of actionable feedback across all questions. And while the limited number of questions examined in this study does not allow for generalizable conclusions to be drawn regarding what type of prototype might be preferable, the findings are consistent with previous studies (Reid et al., 2013) and support a flexible feedback elicitation or design critique strategy that leverages multiple forms of prototypes.

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