PROTOTYPING FOR CHILDREN: UNDERSTANDING HOW FIDELITY AFFECTS CHILDREN'S COMPREHENSION OF PROTOTYPES

Codner, Andria Carolynn;
Lauff, Carlye Anne

University of Minnesota-Twin Cities

ABSTRACT

Testing prototypes with intended end users is critical to the design process. There is limited research on testing prototypes with certain types of end users, specifically children for toy products. Additionally, prototypes evolve in fidelity throughout a project, adding to the complexity in developing best practices for prototype testing. This paper analyzes children's understanding of physical prototypes at various levels of fidelity throughout a university semester-long design project developing wooden toys. Through analyzing students' feedback on their prototype testing sessions, aspects of the prototypes that aid or inhibit children from understanding both form and function are uncovered. These aspects relate to Norman's principles of interaction and their inclusion in prototypes, specifically mental models, signifiers, and affordances. This paper suggests to include these principles in prototypes early in development to guide the user during testing. The goal of this research is to be a resource for those developing products for children, as well as adding knowledge around prototyping testing at various levels of fidelity.

Keywords: Design methods, Design practice, Industrial design, Children

Contact:
Codner, Andria Carolynn
University of Minnesota-Twin Cities
United States of America
banke122@umn.edu

Cite this article: Codner, A. C., Lauff, C. A. (2023) 'Prototyping for Children: Understanding How Fidelity Affects Children's Comprehension of Prototypes', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.301

1 INTRODUCTION

"A picture is worth a thousand words. Only, at IDEO, we've found that a good prototype is worth a thousand pictures" (Kelley, 2001). This quote is illustrative as to how prototypes aid in communication. But what happens when the prototype is a thousand blurry pictures or 500 blurry and 500 clear pictures? It would require more interpretation from the users and have more variety in the users' understandings of the designer's intentions. This is the aspect of prototype fidelity, the degree to which the prototype clearly represents the intended final product (Virzi, 1989). In this paper, we explore fidelity and its effect on children's understanding of physical prototypes. Children are a specialized group of end users with their own experiences, knowledge, and abilities. Because children are still growing and learning, their interactions with prototypes are often different from adults. In the literature, there is a gap in understanding how low-fidelity prototypes affect children's feedback. Our aim is to help fill this gap by answering the question, "How does the fidelity of a prototype affect how children understand the prototype?". Using data gathered from a toy design studio class, we analysed the self-reported prototype testing results from the students, interview transcripts, and other primary documents from the class to answer this question. This paper builds off a prior literature review on usability testing with children (Banker and Lauff, 2022). This work is part of larger research studies that focuses on understanding how prototype fidelity can influence the communication between different stakeholders with the hopes of aiding designers in efficiency when testing children's products (Lauff et al., 2020; Krishnakumar et al., 2022).

2 BACKGROUND

2.1 Testing prototypes with children

Prototype testing often occurs with a sample of intended end users. If the product is to be used by children, then children in the specific age group should test the prototype to accurately represent how the design can be improved. Prototype testing with children has its own unique set of challenges (Markopoulos et al., 2008). These challenges include, but are not limited to, children being a vulnerable population that require more awareness, children having shorter attention spans (Altun Ekiz, 2016), and the dissonance in language between researcher and child. Children have shorter attention spans, which makes it more difficult for researchers to gain a depth of information relating to the product as they would an adult. Because children are in the development stages of writing and speaking, with most children learning to read at the age of 5 (van Bergen et al., 2021), they can be inhibited in expressing their thoughts accurately or completely. Therefore, creative solutions are needed to inspire children to speak without creating bias. Because testing with children requires more consideration to the set-up, it is imperative that the designers have prepared a prototype that will allow for insights and feedback from the children. Since prototypes vary in fidelity and execution, it is necessary to better understand how the fidelity of a prototype might influence testing with children.

2.2 Prototype fidelity and its effects

Fidelity is often referred to as the level of refinement or approximation that the prototype is to the final design. Virzi (1989) defines high-fidelity as not being able to distinguish the prototype from the final product. Lower fidelity typically correlates with less expensive materials and quicker production of the prototypes while high-fidelity prototypes are likely to be made from similar or the same materials as the final product and more precision and accuracy is given to the production of a high-fidelity prototype. Fidelity can relate to a range of factors of a product, such as form and function. When analysing whether fidelity affects the number and variety of usability problems (i.e., effectiveness and efficiency), many researchers did not find a significant difference between various fidelity levels (Catani & Biers, 1998; Sefelin et al., 2003; Walker et al., 2002). With children, the results were similar. When conducting research on mobile games with children aged 7-9, Sim et al. (2013) found that game designers could successfully evaluate paper prototypes (i.e., low-fidelity) with children. When studying user satisfaction and the emotional response to prototypes, Sauer and Sonderegger (2009) did not find any variance between fidelity level's effect on user emotions. However, one paper found that users overcompensated for deficiencies in aesthetics, rating low-fidelity prototypes higher than high-fidelity prototypes or even the final product (Rueda et al., 2013; Sauer & Sonderegger, 2009). Even though users made more comments on aesthetics with low-fidelity prototypes, Walker et al. (2002) concluded that practitioners

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

can conduct usability tests with whatever medium and fidelity aligns with their needs. One impact of higher fidelity form is that users predict better usability (Brady and Phillips, 2003; Norman, 2004; Rueda et al., 2013; Tractinsky, 1997; Uebelbacher et al., 2013). This means that users are biased in their perception of high-fidelity form. These papers serve as a strong foothold for the direction of this research presented in this paper. Only one paper was specific to children and all the papers related back to aspects of HCI (human-computer interaction). This project will add to the research by studying children's prototype testing with physical, analog products (Banker and Lauff, 2022), understanding how prototype fidelity affects their understanding of prototypes.

3 THEORETICAL FRAMEWORK

The guiding framework for this research is Lauff et al.'s (2020) prototypes as critical design objects, specifically used as tools for communication. In this framework prototypes are given meaning and act as a language when put into various social contexts. Lauff et al. (2020) discussed the notion of "encoding and decoding" messages through prototypes. What this means is designers encode prototypes with what they want to communicate to others and then stakeholders decode the prototypes and re-encode with their own interpretation. In the context of this paper, we look at how children view prototypes and how the objective communication of the prototype is decoded by the children, re-encoded back to the designer, and then reinterpreted into design decisions. The other perspective that frames this research, specifically the data analysis, is the fundamental principles of interaction (Norman, 2013). These six principles are affordances, signifiers, constraints, mappings, feedback, and conceptual models. From these, we used three (affordances, signifiers, conceptual models; chosen by their alignment to the arising themes in the findings) to help analyze the understandability of prototypes during testing with children. Affordances are the relationships the user constructs with the object that explains how the object is to be used. Signifiers are the designed ways that guide people through using a product by aiding in understanding the various affordances. Lastly, conceptual models, also known as mental models, are the explanations or understanding of a topic each person has based on their lived experiences. These principles aid in discoverability of the functions and forms of the prototype. Discoverability directly informs the decoding process of prototypes as critical design objects. Combined, we are uncovering how prototypes are used as a communication tool between different stakeholders, specifically the relationship between designers and children as the intended end users, and how elements of the prototype fidelity impact that understanding during testing.

4 METHODOLOGY

4.1 Data collection

Data for this research was collected during a semester-long (16 weeks) four-credit interdisciplinary studio design course at a large, public university in the United States. This class brings together students from several disciplines, including engineering, product design, and business to design a new product. There were 45 students in the course who were divided into nine teams with five students per team. The goal of this class was to design and produce a toy made from rubberwood for the toy company, PlanToys, based in Thailand (PlanToys USA, 2022). PlanToys was the client for the project and is currently the only net-neutral toy company in the world. The company has been around since 1981 and they have more than 500 products. The students were given three major prototyping checkpoints throughout the semester. At the first checkpoint, the students were asked to create five "sketch models" or low-fidelity prototypes of five different ideas. At the second checkpoint, two of the five previous ideas were refined, and the prototypes were presented again in higher fidelity versions based on feedback from checkpoint one. One of those two designs was then presented at the final third checkpoint. At this final checkpoint, the students presented a high-fidelity, looks-like and works-like prototype model. PlanToys attended all three checkpoints and provided feedback on the prototypes, along with faculty, teaching assistants, and industry professionals.

The researchers attended the class in the first weeks of the semester to introduce the research project and goals, including what was expected of each team (surveys, interviews, documenting process and prototypes and sharing that information). At each of the three prototype checkpoints, the teams were required to conduct prototype tests with three different types of key stakeholders for each of the

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

prototypes, including end users (children), parents of children, and experts in product design. The students were instructed to choose end users that were within the intended age group of their product, which ranged from 0-18-year-olds. This intentional testing with different groups of stakeholders is part of our larger research project. In this paper, we only report and discuss testing with children as the intended end users. The teams were required to fill out a survey designed by the research team after each prototype test. The survey included questions relating to the feedback received, the set-up and circumstances of the test, and how the feedback affected future iterations. At the end of the semester after checkpoint three, interviews were conducted with a member of each of the nine teams. The interviews were conducted over Zoom, lasting about 30 minutes each. The goal of the interviews was to get more insight into the perspectives of the students about the projects and prototypes, understanding their testing set-up, how the usability testing sessions went, what they learned from those sessions, and how well the participants understood the prototypes. These interviews were audio and video recorded, and an auto-transcription of the conversation was recorded. We also collected documentation of the teams' progress throughout the semester through a shared Google Drive folder where all pictures, videos, and other design resources were stored. Combined, data was collected from surveys, interviews, and team documentation of the process. All this data was used during analysis.

4.2 Data analysis: prototype testing

In our analysis, specific questions from the survey were explored along with the responses from the interviews with each team as well as documentation of prototypes in the shared Google Drive folders. The survey results that we included in the analysis for this paper, included responses to the prototype testing sessions with children from checkpoints one (38 responses) and three (9 responses). See Figure 1 for an overview of the prototype checkpoints. While the survey has 15 questions per test, we focused on analysing two survey questions in this paper from each prototype test with children: 1) What verbal feedback did you receive? and 2) What nonverbal feedback did you receive? The students' summations of the verbal and nonverbal feedback at each checkpoint were analysed to understand if the children understood the prototype or not in terms of form and function. Evidence was found and documented to support whether the children understood the prototype or not. For the prototypes that were not understood, that feedback was then analysed for its root cause, understanding if it was not understood due to the fidelity or other reasons. We analysed this feedback through the lens of the principles of interaction (Norman, 2013), specifically, conceptual models, signifiers, and affordances. Additionally, the responses to the survey were analysed in the context of those themes in the first checkpoint prototypes and then compared with an analysis of the last checkpoint prototypes to look at prototype fidelity's influence. These findings were documented in a Google Sheet to track the analysis. In addition to analysing the survey questions, data from interviews and first-hand experience notes from students on their testing experience were analysed to triangulate the children's understanding of the prototypes.

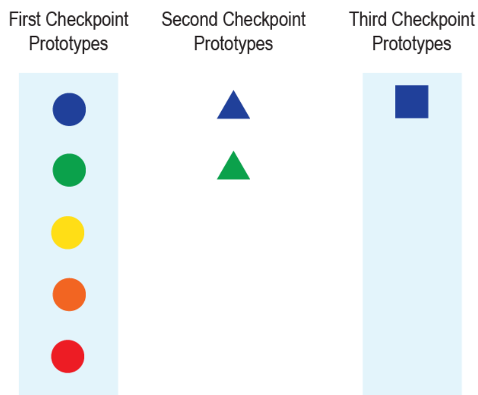

Figure 1. Overview of prototype checkpoints used for analysis. The prototypes that are the same colour indicate that the idea travelled into the next round. The highlighted portion in light blue represents the prototypes we analysed for this paper from Checkpoint 1 and 3.

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

4.3 Determining prototype fidelity values (form and function)

The goal of this paper is to demonstrate how well the children understand prototypes at the lowest fidelity (checkpoint one) versus the highest fidelity (checkpoint three). However, because the teams made higher fidelity prototypes than required in the first round, the prototypes' form and function fidelities were determined by a combination of survey results and a structured analysis. At checkpoint one, the form fidelity was determined on a scale of 1-5 (1 = poor and 5 = excellent) from the results of the question asking about the "Model Planning and Construction Quality" of each prototype. All responses were collected via a Google Survey during the checkpoint 1 presentations and these were completed by the instructors and client of the class. At checkpoint three, the form fidelity was determined on a scale of 1-5 (1 = low quality/entire prototype is poorly constructed and 5 = high quality/entire prototype is well constructed) from a survey that was sent out to the instructors of the class. The function fidelity at checkpoint one was determined by the researchers using this specific scale: 1 = no function, 2 = less than half the functions work but with errors, 3 = half of the functions work moderately well, 4 = most functions work fairly well, and 5 = all functions work well. The function fidelity at checkpoint three was determined on a scale of 1-5 (1 = poor and 5 = excellent) from the results of the question, "The prototype looks and works like a real product." All responses were collected from a Google Survey taken during the final presentation which was completed by audience members, including lab instructors, industry, and the client. From this, the average fidelity was compared to understand whether there is a significant difference between the understanding of children between checkpoints one and three.

4.4 Research limitations

There were several limitations of this research. At the beginning of the semester, the teams were given tips on how to conduct testing with the children; however, they were not required to follow a specific set up. With this independence, the teams could conduct their prototype testing sessions in a variety of ways, including variance in set-up instructions and locations. The depth of the survey responses was also dependent on the students, with some teams filling out lengthy responses and other teams giving shorter, less descriptive answers. Additionally, students have their own perspectives and biases when observing and reporting the results of the testing. We worked under the assumption that students reported factual information about their tests, but we were not able to observe the tests first-hand to verify. Another limiting factor is the number of prototypes at each checkpoint. Teams were required to have five prototypes at checkpoint one (45 total) and one prototype for checkpoint three (9 total), which means we had five times the data to analyse from the first checkpoint. Lastly, teams produced much higher fidelity prototypes than were required for checkpoint one. The expectation for the class was producing "sketch models", but teams instead produced much higher quality models. While the prototypes in checkpoint one were still lower fidelity then checkpoint three, they were still much higher quality than we expected. The researchers evaluated the fidelity of each prototype based on form and function to articulate the differences more clearly between stages. In this numerical evaluation, more research is needed to clearly define the level of difference between fidelity in each prototype.

5 RESULTS

The guiding research question for this paper is "How does the fidelity of a prototype affect how children understand the prototype?" To answer this question, we analysed prototypes from the perspective of form and function. For each prototype created, we looked at the level of understanding for children related to these two factors. Seventeen prototypes out of a total of 38 prototypes in the first round were not well understood by children in terms of form, function, or both aspects of the prototype. Initially, looking at the average fidelity of the prototypes, there is little difference between the average fidelity of prototypes not completely understood and the average of all the prototypes at the first checkpoint (as seen in Table 1 in Section 5.4). However, we found it important to look at the qualitative data from surveys and interviews to clarify the relationship of fidelity and what is causing children to not understand specific prototypes. The different degrees of misunderstanding of prototypes are: 1) not understanding prototypes at all (either in form, function, or both), 2) not understanding parts of the prototypes, or 3) not understanding prototypes at first and then later understanding the prototypes by the end of testing. In analysing the reasons children did not understand the prototypes, we used three principles of interaction, mental models, signifiers, and

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

affordances (Norman, 2013), to deepen our understanding of what elements of the prototypes impacted children's understanding.

5.1 Mental models

Mental models are construction blocks to design; they are the “conceptual models” that people organize and that “represent their understanding of how things work” (Norman, 2013). It is with the use of mental models that people can interpret designers’ intentions in products. There is an inconsistency found between what the teams believed were accurate and necessary mental models in the product and what the children’s mental models were, especially in relation to understanding form. In the qualitative data from the survey and interviews, there are instances where the information presented in the prototypes does not match the mental models that the children have. This is because there were not enough familiar characteristics to correctly associate with their mental models, the information presented simply did not match their current mental models, or they did not yet have a mental model for the concept.

In one instance of prototype testing at checkpoint one, a team was testing their “explorer kit” prototype (Figure 2-A), and the child they were testing with, “...didn’t know how to properly take off the telescope. [They] just pulled on the string really hard.” The child had their own model of what should work, of how to take off the telescope by pulling the string. When the child tried this idea, it did not work because the prototype was not designed based on their mental model but rather a different model of the designers. In another example, a child was testing a “floating train” (Figure 2-B). The team started the testing experience by explaining what the prototype was and the intent of the toy. However, the child contradicted what the prototype was supposed to be by stating, “It doesn’t look like a train, [it] looks like a steamboat.” If the child had not already been told that it was a train, they would have assumed it was a steamboat. In explaining what the prototype was beforehand, the team directed the child in the right direction, however, if this child had been less verbal and did not state what they thought it looked like, the team would have continued without knowing that critical information. If the information in the prototype is misinterpreted, falling in a different frame of mental models than expected, then the feedback from testing might not help the team adequately progress forward.

When considering potential users’ mental models, the designer needs to consider how much information is necessary to convey the correct meaning of form and function. One team found that “[the] children… didn’t seem to pick up on the camera influence…” when evaluating a toy that was modelled to be like a camera (Figure 2-C). The toy had a simplified form that was inspired by a camera, a body and a lens, however, there were not many intricate camera details, such as buttons to push or clear lenses to make it appear more like a camera. One prototype (Figure 2-D), that was partially understood by children during testing, had pieces that were supposed to represent bears. This spinning toy had a range of sizes of stackable bears that would spin through a threaded pole. While the one centre piece was a solid bear, the remainder of the pieces were abstracted outlines of the bear shape. The students stated that the ears were helpful to get the idea across, but the pieces that were an outline of a bear were “confusing [to the children] as to what it is actually”. This required a mental leap for children from the solid bear shape to the outlined bear structure, which limited the quality of the feedback received during testing.

(A) (B) (C) (D) (E) (F)

Figure 2. Checkpoint 1 Prototypes: (A) Explorer Kit, (B) Floating Train, (C) KaleidoCam, (D) Spinning Species, (E) Tic-Tac-Toe, and (F) Topographic Blocks

There is so much that children must still learn and, therefore, they do not have a formed cognitive representation of that unknown information. For example, a team designed a tic-tac-toe game using specific kinds of bugs as their characters (Figure 2-E). While the children understood the basic premise of tic-tac-toe, the children did not know the specific types of bugs (other than the ladybug), but they understood they were representations of bugs. In another example, the children found the specific colours and forms used confusing (Figure 2-F). The team used representative colour and geometric

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

shapes to represent topography (Figure 2-F). The children did not understand that representation of colour/shape and its reference to topography, likely because they had not been taught those topics yet. In situations where children do not have already existing mental models, there is a room for the toy to be educational. Children have their own set of mental models. If the designer does not consider a child's mental models, they may produce prototypes and products that will not be understood.

5.2 Signifiers

Signifiers are the designed ways that guide people through using a product (Norman, 2013). When looking at the effect of signifiers in this data, we observed that signifiers have a large impact on the depth of understanding that the children have when interacting with prototypes. In several prototypes, there was feedback that demonstrated a lack of signifiers. In many instances the lack of signifiers impacted the very start of using the prototype. One team noted (Figure 3-A), "[The child] didn't know where to start the ball." Another team states (Figure 3-B), "[The child] didn't initially know what to do to play with it," and, in the context of another of their prototypes (Figure 3-C), "[The child] seemed unsure where to enter." This uncertainty is related to not having enough information. The children were not given the information in the prototype to know where to start. The risk of not knowing where to start is not being able to give comprehensive feedback on the entirety of the prototype. As one of the team's mentioned (Figure 3-D), "The kid was unsure which side of the launcher to use for the token and which to hit, that caused confusion." In this quote from the data, we see confusion for the child as an outcome of not having signifiers for the function in the prototype. Nothing signified to the children what was the correct layout for the parts of the toy. In another example of using the prototype incorrectly, a child holds a prototype in the air to use it when it was designed to be used on the table. The child could not determine the right orientation of the toy. Some prototypes took a minute to understand; it is acceptable to take some time when learning a new prototype (or product), however, it can be detrimental if a model takes too long to understand. We saw how the use of signifiers may aid in quickening the process of understanding the prototypes' objectives, which then enhances the feedback during testing. There were also moments in the feedback where the children did not know how to use the prototypes at first, but then, with instruction, they learned. The instruction from the teams can be likened to verbal signifiers. The use of verbal signifiers allows the children to understand the prototype more clearly, but it does come with its own risks, such as bias toward the prototype.

(A) (B) (C) (D)

Figure 3. Checkpoint 1 Prototypes: (A) Xylophone Staircase, (B) Chipper Music Player, (C)Turtle Rider, and (D) Pollin-Aimers

5.3 Affordances

Affordances in design are the different functions the object can be used for, whether intentional by the designer or not (Norman, 2013). When analysing the surveys and interviews, we noticed that intended affordances of the prototypes are an aspect of design that can easily be misunderstood by children during testing. In some examples, children did not understand the original affordance encoded by the designer and, therefore, created their own use of the prototype. With two different prototypes, one team noted that both prototypes, which were designed to be stacking toys (Figure 2-F), were used more like puzzles. The team now has the potential to embrace that newfound affordance (i.e., puzzle pieces), but they still do not have feedback on their original intentions (i.e., stacking toys). In other examples, children would not understand the original affordance and, therefore, not interact with that aspect of the prototype until instructed how to do so. The children did not know how to interact with a set of "blanket fort helpers" (Figure 4-A) until the students explained the intent. Both situations can be a disservice to the team because they would not learn about the end user's authentic interaction with the intended function of the design. One team remarks, "He [the child] didn't really see what the use was for in the test tubes [in the toy] as he [the child] asked 'What are these for?'" The team created a "science set" prototype (Figure 4-B) in which there was a microscope and a set of test tubes.

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

Compared to the microscope, which had many moving parts, the test tubes could be seen as an unmoving solid component. Maybe in part due to the juxtaposition of the two objects (dynamic microscope vs. static test tube), the child did not reason what the affordance was in the product.

(A) (B)

Figure 4. Checkpoint 1 Prototypes: (A) Blanket Fort Helper and (B) Science Set

5.4 Comparison of checkpoint 1 and checkpoint 3

To conclude the results of the research question, "How does the fidelity of a prototype affect how children understand the prototype?," we analysed checkpoint three prototypes to understand what affected how the children understood those prototypes, and then compared those findings with what we found at checkpoint one. The number of prototypes at checkpoint three (total of 9) is about 24% the amount of prototypes at checkpoint one (total of 41). This is an important consideration when analysing these results. Looking again at the prototypes that were misunderstood, the fidelity of these prototypes at checkpoint three was slightly higher than the average fidelity of all the checkpoint three prototypes, which was not expected at the onset of this research (shown in Table 1).

Table 1. Average prototype fidelities on a scale of 1 = low to 5 = high in Checkpoint 1 (n = 41) and Checkpoint 3 (n = 9) compared between misunderstood prototypes and all prototypes.

	Checkpoint 1 **Form** Fidelity	Checkpoint 1 *Function* Fidelity	Checkpoint 3 **Form** Fidelity	Checkpoint 3 *Function* Fidelity
Average Fidelity of **Misunderstood** Prototypes	3.3	3.4	4.1	4.4
Average Fidelity of **All** Prototypes	3.6	3.5	4.1	4.3

A reason for not understanding prototypes that was unique to checkpoint 3 is children's confusion with game play. In an interview, a student stated, "I think it was a little harder to explain like with our board game, the rules of the game." The children understood many variables of their mountain game (Figure 5-A), how it was supposed to function and what the different forms were, but the team had a hard time explaining the more abstract concept of the game rules. Another team had difficulty with the children not understanding the goal of their food stacking game (Figure 5-B). The children understood the set up but not how to win.

(A) (B) (C)

Figure 5. Prototypes. (A) Flood Fighters, (B) Sandwich Stackers, (C) Spin Stackers

Other reasons for not understanding at checkpoint three are similar to what was found at checkpoint one. These reasons are related to mental models and signifiers. The reason the children did not understand form was because the children did not have existing knowledge on certain aspects. "They understood it was a game, but I don't think they had what it represented." The students designed this game to represent an ecosystem with rain, plants, and mountains (Figure 5-A). They were trying to teach how adding different aspects on the mountain (like trees) caused the rain (marbles) to be redirected, thus educating

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press

on how landscapes are maintained to protect man made aspects (towns). The children did not understand the more nuanced details of the educational aspects. For the food stacking game, the children did not recognize the foods, not because there was not enough information in the prototype, but rather because those children had not seen that food before (Figure 5-B). Signifiers play a role in understanding at this checkpoint as well. One team saw the children having difficulty with a specific connector function on their toy, Spin Stackers (Figure 5-C). The children did not realize the function was there. In the interview with a team member, the student suggested the need to add signifiers to guide the children in making the relationship between the male and female connector ends.

5.5 Summary of results

The qualities of prototypes that lead to misunderstanding can be found along the spectrum of fidelity. In lower fidelity models, there is a higher chance of not having the right or enough signifiers within the prototype, the use of incorrect or lack of information related to mental models led children to not understand form, and the children missed affordances/functions due to a lack of signifiers. In higher fidelity models, most of the affordances that are not understood are the uses that would normally be guided by a secondary object, such as an instruction packet. One reason children did not understand forms in both high and low-fidelity models was because they had not yet been introduced to a concept. Also, in both fidelities of prototypes, details in the functions were lost because of a lack of signifiers. Through the results of this data, we have learned it is not the quality of the prototype that leads to misunderstanding, but the missing aspects of the prototype.

6 DISCUSSION AND CONCLUSION

Fidelity of a prototype can be defined as the level of refinement of the design when compared to the intended final product; a low-fidelity prototype is less representative of the final design (in form, function, or both), whereas a higher fidelity prototype is closer in representation to the intended product (Virzi, 1989). We aimed to answer the question “How does the fidelity of a prototype affect how children understand the prototype?” Based on our research, our current working answer is that the quality of the prototypes (material choice and how well it is finished in both form and function) does not have much effect on children’s understanding, but the lack of certain features of the prototype could lead to misunderstanding or not understanding of the prototype, specifically in how well those features aid in signifying intent, identifying intended affordance, and matching mental models. If a prototype is missing features in the model that seems to impact understanding more than the quality of prototypes.

Another consideration from our results is the need for more intentionality when considering the use of signifiers and mental models in prototypes for children. This intentionality means the designers consider these aspects throughout the design process, which might require determining the best ways to translate the various variables to the children before building a prototype. For example, when a prototype has a certain function, like pushing a button for a specific interaction, there has to be a path to figuring out that function with the designers creating the "stepping stones" to that path (through the use of mental models, signifiers, and affordances). For the example of the button, a different material, colour, or sticker would be options to signify that something is different about that feature, leading the children to explore that function while testing. When creating a prototype without these metaphorical stepping stones, it becomes a “choose-your-own-adventure” for the children, meaning that children can use their imagination and pretend play to create their own story around the prototype object. It is in these instances that children will find their own solutions to creating a function or they will feel deterred from even trying, meaning that the designer then loses feedback on their original functions/intentions. Considering the aspects in which the prototype itself explains its form and affordances will aid the children in understanding the intentions of the designers. In turn, this will aid the designers in receiving unbiased feedback from the children. At the beginning of the design process for children's toys, designers should be identifying ways to use signifiers and mental models in their prototypes and then find ways to represent those ideas at the onset of prototyping. This could be included as part of the design requirements.

To conclude, this work adds to the literature by suggesting the concept of intentional encoding/decoding of prototypes to aid in communication between two distinct stakeholders, specifically children (as users) and designers. To aid children in properly decoding prototypes, there needs to be the correct use of mental models, signifiers, and affordances in the models. The design team must be intentional with all aspects of the prototype, including the elements of interaction and how certain functional elements are represented, especially if in a lower fidelity model. With this intentionality, the design team will be encoding the prototype with more purpose for the children to correctly decode the intended form and functions, and therefore, give more meaningful feedback during testing sessions. One goal of this paper is to be a resource for designers who are developing products for children by adding to the literature a qualitative analysis of children's understanding of prototypes as communication tools.

REFERENCES

Altun, M., Hazar, M., and Hazar, Z. (2016), Investigation of the Effects of Brain Teasers on Attention Spans of Pre-School Children. International Journal of Environmental and Science Education, 11(15), pp. 8112-8119.

Banker, A. and Lauff, C. (2022), "Usability testing with children: History of best practices, comparison of methods and gaps in literature" *Presented at the DRS2022*, Bilbao. https://doi.org/10.21606/drs.2022.646

Brady, L. and Phillips, C. (2003), "Aesthetics and Usability: A Look at Color and Balance." *Usability News, 5*

Catani, M.B. and Biers, D.W. (1998), Usability Evaluation and Prototype Fidelity: Users and Usability Professionals. Proc. Hum. Factors Ergon. Soc. Annu. Meet. 42, pp. 1331–1335. https://doi.org/10.1177/154193129804201901

Kelley, T. (2001), "Prototyping is the shorthand of innovation" *Des. Manag. J. Former Ser*. 12, pp. 35–42. https://doi.org/10.1111/j.1948-7169.2001.tb00551.x

Krishnakumar, S., Berdanier, C., Lauff, C., McComb, C. and Menold, J. (2022), "The story novice designers tell: How rhetorical structures and prototyping shape communication with external audiences" *Design Studies*, 82, pp.101-133.

Lauff, C.A., Knight, D., Kotys-Schwartz, D. and Rentschler, M.E. (2020), "The role of prototypes in communication between stakeholders", Design Studies, 66, pp. 1-34. https://doi.org/10.1016/j.destud.2019.11.007

Markopoulos, P., Read, J.C., MacFarlane, S. and Hoysniemi, J. (2008), "Evaluating Children's Interactive Products: Principles and Practices for Interaction Designers" *Elsevier*.

Norman, D. (2013), "The Design of Everyday Things: Revised and Expanded Edition." *Basic Books*.

Norman, D. (2004), "Introduction to This Special Section on Beauty, Goodness, and Usability" *Hum.-Comput. Interact*. 19, pp. 311–318. https://doi.org/10.1207/s15327051hci1904_1

PlanToys USA - Wooden Toys for Kids (2022), PlanToys USA. URL https://www.plantoys.com/ (accessed 11.18.22).

Rueda, D., Hoto, R. and Conejero, A. (2013), "Study of the Influence of Prototype Aesthetic Fidelity (A Realism Factor) in Usability Tests" *Human Factors in Computing and Informatics* 15, pp. 122-136

Sauer, J. and Sonderegger, A. (2009), "The influence of prototype fidelity and aesthetics of design in usability tests: Effects on user behaviour, subjective evaluation and emotion" *Appl. Ergon.* 40, pp. 670–677. https://doi.org/10.1016/j.apergo.2008.06.006

Sefelin, R., Tscheligi, M. and Giller, V. (2003), "Paper prototyping - what is it good for? a comparison of paper- and computer-based low-fidelity prototyping" *in: CHI '03 Extended Abstracts on Human Factors in Computing Systems, CHI EA '03. Association for Computing Machinery*, New York, NY, USA, pp. 778–779. https://doi.org/10.1145/765891.765986

Sim, G., Cassidy, B. and Read, J.C. (2013), "Understanding the fidelity effect when evaluating games with children" *in: Proceedings of the 12th International Conference on Interaction Design and Children*, New York, USA, pp. 193–200. https://doi.org/10.1145/2485760.2485769

Tractinsky, N. (1997), "Aesthetics and apparent usability: empirically assessing cultural and methodological issues" *Proceedings of the 1997 Conference on Human Factors in Computing Systems*, CHI. pp. 115–122.

Uebelbacher, A., Sonderegger, A. and Sauer, J. (2013), "Effects of Perceived Prototype Fidelity in Usability Testing under Different Conditions of Observer Presence" *Interact. Comput*. 25, pp. 91–101. https://doi.org/10.1093/iwc/iws002

van Bergen, E., Vasalampi, K. and Torppa, M. (2020), "How Are Practice and Performance Related? Development of Reading From Age 5 to 15" *Read. Res. Q*. 56, 415–434. https://doi.org/10.1002/rrq.309

Virzi, R.A. (1989), "What can you Learn from a Low-Fidelity Prototype?" *Proc. Hum. Factors Soc. Annu. Meet*. 33, pp. 224–228. https://doi.org/10.1177/154193128903300405

Walker, M., Takayama, L. and Landay, J.A. (2002), "High-Fidelity or Low-Fidelity, Paper or Computer? Choosing Attributes when Testing Web Prototypes" *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 46, pp. 661–665. https://doi.org/10.1177/154193120204600513

https://doi.org/10.1017/pds.2023.301 Published online by Cambridge University Press