Assessing a Virtual Platform's Effectiveness in Exploring Mental Models of Robot Design*

Weston Laity[1], Robel Mamo[1], Benjamin Dossett[1], *Student Member, IEEE*, Maisey Toczek[1], Jordan Sinclair[1], Nicole Train[2], Daniel Pittman[2], *Member, IEEE* and Kerstin S. Haring[1], *Member, IEEE*

***Abstract*— This work presents our strategy for investigating the fundamental guidelines and theories related to robot mind perception, and for establishing a metric for mental models, using our web-based tool, Build-A-Bot. We also discuss the effectiveness and efficiency of our platform by virtue of its inclusive design and its ability to visualize the user's intended representation of a mental model for a robot through a 3D game-like interface. We conducted an observational user test study to assess if the website and the embedded robot building tool are effective and efficient to use for users. We found that the design of the robot creation platform and its associated website are considered intuitive and effective by a majority of our survey population. The Build-A-Bot platform successfully provides the ability for users to visualize their ideal representation of their mental model through an interactive game. Based on the obtained data, we propose further steps to optimize the Build-A-Bot platform for universal usability.**

I. INTRODUCTION

Robots come in a wide variety of designs. Often, robot designs are driven by the functional requirements of the robot, such as accommodating the operational hardware necessary for it to perform its given function. However, a robot designer must consider not only the functionality of the robot, but also how its design is *perceived* by its users. Initially, this perception is shaped by the outward appearance of the robot [1]. Research has begun to evaluate how people form mental models of robots [2], [3], [4], [5], [6], [7] and we postulate that each aspect of the design of a robot will influence the mental model created by people who interact with it [8].

Mental models are considered an explanation of someone's thought process about how a robot works [9], and are based on a small set of fundamental assumptions [10]. Mental models are formed by an individual based on their perception and understanding of the robot [11], and, more generally, form the basis for human reasoning and decision making. It would seem highly advantageous for effective and efficient Human-Robot Interaction (HRI) to design robots in a way that evokes an appropriate mental model with the user, especially when that robot's purpose is to interact with people on a regular basis. However, mental models are often based on unquantifiable, obscure, or incomplete facts [12], based on selective perception [13], and are very limited compared to the complexities of human-robot interactions. Mental models are also flexible [14], meaning that they adjust and are likely to change in short and long-term interactions with the robot, and with the change in the mental model, the corresponding behavioral responses also change. This makes it very challenging to develop a mental model metric in HRI [6]. Currently, designers have limited guidelines and theories to work from, as it is unclear how a mental model or perception of a certain robot's capability is facilitated by its design. This paper discusses our approach to creating fundamental new knowledge on robot mental models.

Robots of the future are expected to be highly social and cooperative. These robots will face high degrees of anthropomorphism given their potentially human-like levels of communication. What physical features should these currently nonexistent robots have to create appropriate mental models in their users?

These questions about how robots should look in order to increase user acceptance led us to develop the Build-A-Bot platform. The Build-A-Bot platform is a highly accessible online tool that allows anyone to build and customize a stationary 3D robot, with the hope of capturing the user's mental model projection. With the data collected by the tool, our research team aims to isolate key features of the design of physical robots that trigger an appropriate mental model for a given trait.

When designing the Build-A-Bot platform, we considered it critical to ensure that our application was created in an accessible manner that allowed a broad demographic of users to interact with the platform. Specifically, we considered the following design aspects when building the platform:

- The platform controls should be easily identified by anyone, regardless of their language proficiency
- Navigation through the platform's interface should be effective and in line with existing features that users encounter on other websites on the Internet
- The platform should provide feedback after each user input to ensure that it is clear what action takes place after a given user interaction

If we fail to meet these criteria, the user will not be able to effectively build a robot, or contribute to our collection of robotic designs. Because of this, it is critical to our research that we ensure universal understanding within each platform feature that is developed. To best meet this goal of universal understanding, it is important to use patterns that users are

*This work was supported by the University of Denver's Professional Research Opportunities for Faculty (PROF) under grant # 142101-84994

[1]Weston Laity, Robel Mamo, Benjamin Dossett, Maisey Toczek, Jordan Sinclair, and Kerstin S. Haring are with the Ritchie School of Computer Science and Engineering, University of Denver, Denver, CO 80210, USA, firstname.lastname@du.edu

[2]Nicole Train and Daniel Pittman are with the Department of Computer Sciences, Metropolitan State University of Denver, Denver, CO 80204, USA dpittma8@msudenver.edu

already familiar with in other software. We must also confirm this understanding with analysis, user testing, and survey information. In this paper, we focus on the survey results from our first overall platform test.

The evaluated version of the Build-A-Bot platform is fully functional for building robots. At this time, we felt it appropriate to run a survey against our platform to ensure that everything is easy to use and understand, and that we are not missing any integral features. This paper details our findings on the usability and intuitiveness of our own platform.

II. Related Work

A. Robot Design for Collaborations in HRI

In human-robot teaming, research has emphasized the importance of having similar or shared mental models about robots [7], [6]. This implies that having a mental model of a robot, to some degree, leads to the notion of empathy towards robots. There is evidence that people show more empathy for more human-like robots [15], [16], [17]. This includes language about damaged robots [18], apathy toward hurting robots [19], concern for robots that appear to be under duress [20], and increased prosocial behaviors towards robots [21], [22]. This idea highlights the need for guidelines for the design of anthropomorphic features to ensure that mental models are fully realized through physical design.

B. Interface Design

There are many existing guidelines for creating informative and inclusive user interfaces, which we refer to when creating and grading our platform. The eight golden rules of interface design [23] provide principles of how interfaces should be presented. Although we do not discard any of these, in this paper we focus on universal usability (to an extent to which it makes sense for our platform), for example, permitting easy reversal of actions and keeping our users in control. If we can achieve all of these, we believe that our exploratory test should be accessible to all survey users. Some additional guidelines that we consulted included Microsoft's style guide [24] for learning a complex skill or task. This describes the features that should accompany the platform to help users, including training, tutorials, interactive graphics, and more. The tool itself is accompanied by a tutorial explaining all the features of the game, available at any time before or during the process.

C. Universal Usability and Accessibility

Usability is a term from Human-Computer Interaction (HCI) and refers to the inherent characteristics of an interface that allow any user to use it efficiently, easily, practically and satisfactorily. Accessibility can be regarded as a subset of usability problems; however, accessibility encompasses more than just usability [25]. The concept of "universal usability" encompasses both accessibility and usability and aims to create interfaces with the widest possible range of people, including those with special needs [26]. The use of auditory clues has been shown to be important for more accessible design [27] by using sound effects for actions. Furthermore, multimodal feedback has been shown to improve the performance of fully sighted users and offers great potential to users with visual impairments [28] allowing for more advanced interface designs [29]. Additionally, lowering the accuracy of drag-and-drop interactions has been shown to reduce error rates in older adults [30]. Although a comprehensive account of accessibility guidelines goes beyond the scope of this article, we developed an interface prototype and evaluated usability and user experience levels through an iterative user-centered design lifecycle [31].

III. Methodology

A. The Build-A-Bot Platform

The platform is publicly available on the Web at https://www.dubuildabot.com. On the homepage of the website, new users can sign up and existing users can log in (see Figure 1). To create a robot, users must be registered and logged into the application. The homepage has four tabs at the top where users can find additional information about the project, the research team, and published works related to the project. The website was built using MongoDB [32], Express.js, Angular [33], and Node.js (MEAN).

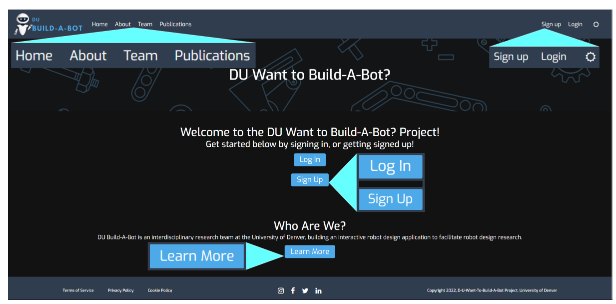


Fig. 1: A screenshot of the Build-A-Bot homepage with the tab navigation at the top, log in and sign up at the top and in the middle of the screen, and the learn more button at the bottom, enhanced for better readability.

After logging in, the user can navigate to the robot building tool by clicking on the "Build A Bot" button which leads them the locations shown in Figure 2. The robot building tool is a 3D Unity application embedded in the website. The robot building tool is organized into three sections. On the left-hand side of the interface (A in Figure 2), a menu with three main categories of robot parts is displayed: head, torso and legs. Each category is further subdivided. For example, the "head" category expands into items such as eyes, hats, and noses by clicking on the "head" icon. Users can select these parts and drag them from the menus into the scene in the middle of the screen to customize their robot designs. To let users customize their robot designs, we have incorporated a menu on the right-hand side menu (B in Figure 2). This menu provides a radio button list for users to control the orientation, scale, and position of the selected parts within the scene. At the middle bottom of the interface, there is a menu (C in Figure 2) that features a color slider that applies to selected robot parts. The icons below are tied to actions (from left to right: undo an action, redo an action, trash selection, duplicate selection, save the design, submit the design, main menu). Robot parts can be attached to each other (see 1 in Figure 2) or be separate (see 2 in Figure 2). Each part has several predetermined locations where it can be attached to another part. This action is supported by a sound effect (that is, a snap-like sound), a visual effect (that is, yellow sparks), and a consistent color scheme (that is, red and blue silhouettes for unattached and attached parts respectively).

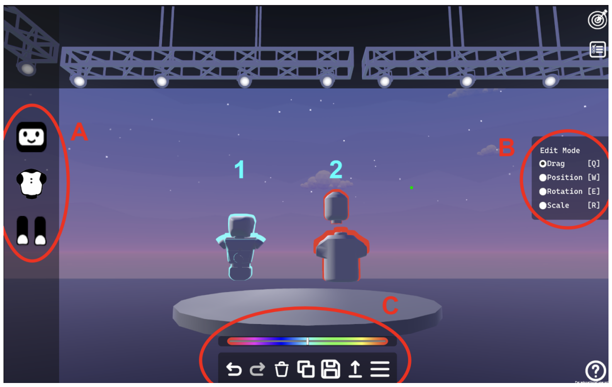


Fig. 2: A screenshot of the robot building tool with the part selection for drag and drop and the left side, a demonstration of an attached (1) and unattached part (2), the edit gestures on the right side, and the coloring and action menu on the bottom of the screen.

Before starting a new robot design, the user is presented with a *challenge card* that prompts the user to build a robot with a certain capability that corresponds mainly to two different dimensions of mind perception: agency and experience [34]. For example, the prompt might ask a user to design a robot that can memorize or plan, or experience hunger, pain, fear, joy, or pleasure. The prompt might also ask for the opposite (for example, a robot that is *not* capable of experiencing love) to gain a broad representation of robot designs along the dimensions of mind perception.

B. Experimental Design

We ran an observational user test study on the Build-A-Bot platform to assess if the website and the embedded robot building tool are effective and efficient to use. To gain a broad understanding of the user experience of creating a robot, we recruited participants online through Amazon Mechanical Turk (MTurk) and instructed them to create a robot and report their experience in a survey. The survey asked about the general process of designing a robot, user demographics, and detailed questions about each feature regarding its ease of use, usefulness, and intuitiveness. The observational study was designed to provide insight into 1) the navigation to the homepage to find the robot builder and 2) creating a robot from the provided building blocks.

Participants first agreed to participate through an informed consent process approved by the Institutional Review Board of the University of Denver. The participants were then instructed to visit the homepage, create an account, and design a robot. There were no explicit instructions on how to perform these steps, as it was important for this study to simulate how a new user experiences and navigates to the robot-building tool. The survey included a timer that prevented participants from going forward for seven minutes to ensure that they spent enough time exploring the website and building a robot. Participants were instructed to return to the survey after they submitted their robot design.

The following set of questions focused on each feature of the robot building tool and how well users were able to navigate the interface to inform the next steps in our iterative design process. A complete overview of all the features evaluated can be seen in Table I.

TABLE I: Overview of all homepage navigation and all robot building features that were assessed for ease of use, intuitiveness, and usefulness.

Ease of use, Intuitiveness, Usefulness		
Play	Options	Tutorial
Quit	Prompt	Parts Toolbar
Color Slider	Undo	Redo
Delete Part	Duplicate Part	Save
Submit	Menu	Drag
Position	Rotation	Scale
Home	About	Team
Publications	Sign Up	Login
Light/Dark Mode	Learn More	Log Out
Build A Bot	Your Bots	Profile

C. Feature Usability

The survey evaluated how well users were able to identify the purpose of each feature and whether these features added value when interacting with the application. A *feature* refers to any element that is associated with a functionality (e.g. a button). For the robot building tool, the relevant features included all gestures, design manipulations, and menu options within the building tool. The website features included its core functionality, such as log-in and log-out, navigation, and other navigation features. We ask the same set of questions for each characteristic surveyed. Each question could be answered on a 5-point scale from “very easy” to “very hard” and included the options to indicate that the participant did not recall using the feature or did not use it.

- How easy is it to understand the purpose of this feature?
- How would you describe the purpose of this feature?
- How easy is the feature to use?
- How useful was the feature when building a robot?

To mitigate our own design biases, we added a question asking what user groups participants believed the platform would best suit. This question was expected to provide better insight if we can achieve our goal of creating a robot platform that enables a broad spectrum of user demographics to design robots. As this was our first full-platform test, it was important to ask users as the last question if they would provide additional recommendations for anything they think we might have missed, to better inform our next iteration of platform implementation and testing.

D. Music and Sound

The platform includes music and sound elements to create an immersive space for creative design. Video game music has been found to influence immersion, both positively and negatively [35]. By default, we included music that continuously plays a background track, and users can choose to mute it. Certain actions and gestures in the interface also have a sound effect, for example attaching a robot part to another part. Our goal is to understand more about how users felt about the music and whether it helped or distracted them in building a robot. We asked users if they noticed background music and other sound effects, if they turned off the music in the menu, and if they found the music distracting.

E. Runtime Environment

In preliminary testing, we found occasional unexpected problems, for example, lag or platform freezing. To evaluate whether this is a persistent problem, we collected information on the computer specifications of the participants. We asked what device type they used, what operating system they had, how many cores their processor had, how much memory their computer had, and whether they experienced performance issues during the platform test.

IV. Results

A. Participants and Demographics

Three participants did not complete the survey and were excluded from the analysis, leaving 47 complete surveys. The ages of the participants ranged from 25 to 61 ($M = 39.95$, $SD = 9.5$). 18 participants identified as women and 29 as men, and none identified in the other options, including a "Prefer not to say" option. As our platform resembles an interface commonly seen in 3D modeling, robotics, and video games, we asked for any experience in those areas (binary yes-no response). 31 stated that they had experience in these areas, and 16 stated that they did not. We conducted a chi-square test to evaluate whether previous experience influences the rating of feature difficulty. The aggregate results of the difficulty ratings are shown in Fig. 10. The input data can be seen in Table II and Table III shows the results. All results were found to be nonsignificant with $\chi^2(4, N = 47) < 9.488, p > 0.05$.

TABLE II: Chi-square input values for the "drag" feature by prior experience (Prior Exp).

Responses for "drag"						
	Very Easy	Somewhat easy	Neither	Somewhat hard	Very Hard	Row Total
Prior Exp Yes	9	6	1	0	1	17
Prior Exp No	7	2	1	0	0	10
Col Total	16	8	2	0	1	27

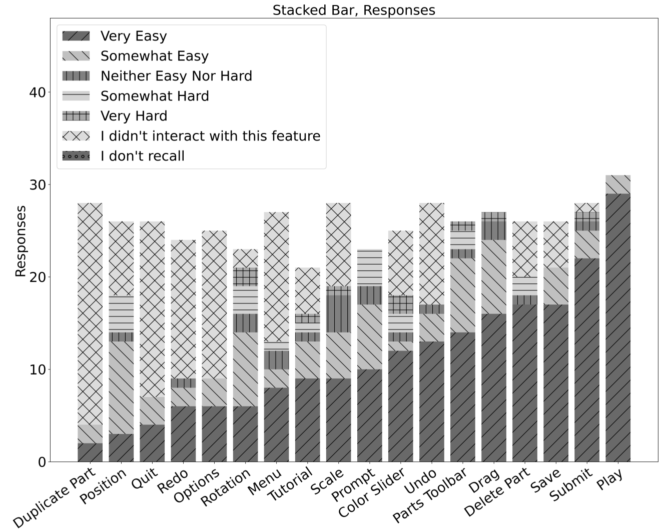


Fig. 3: The aggregate count of ratings on a 5-point scale ranging from "Very Easy" to "Very Hard" for evaluated features, including the times participants did not recall or did not interact with the feature.

TABLE III: Chi-square statistic values for each feature evaluated by prior participant experiences. With a $df = 4$ a critical value < 9.488 would be needed for significant results with $p < .05$.

Game Feature	chi-squared	p-Value	Effect Size
Drag	1.54	0.92	0.24
Delete Part	1.51	0.82	0.28
Quit	2.10	0.72	0.55
Duplicate Part	0.00	1.00	0.00
Submit	2.21	0.70	0.29
Rotation	1.74	0.78	0.29
Play	0.87	0.93	0.17
Undo	2.67	0.61	0.40
Save	0.64	0.96	0.18
Scale	0.31	0.99	0.13
Color Slider	2.22	0.70	0.35
Redo	1.29	0.86	0.38
Prompt	2.66	0.62	0.34
Parts Toolbar	5.55	0.24	0.46
Tutorial	3.32	0.51	0.46
Options	0.00	1.00	0.00
Menu	4.20	0.38	0.57
Position	0.89	0.93	0.22

B. Website Navigation

The navigation of the website was another key area. We wanted our website to be easy to navigate. We aim to achieve this through user interface designs that enable users to access features without having to memorize features or having to learn the website navigation. We evaluated the navigation from our website's homepage to the robot-building tool for usefulness, intuitiveness, and ease of use. This was performed for all features of the website listed in Table I. We found that 55% of our participants rated it "Easy"/"Very Easy" to navigate from the homepage of the website to the robot building tool. However, as shown in the frequency count in Figure 4), there is a large number of users, 32%, who found it "Difficult" / "Very Difficult" to navigate

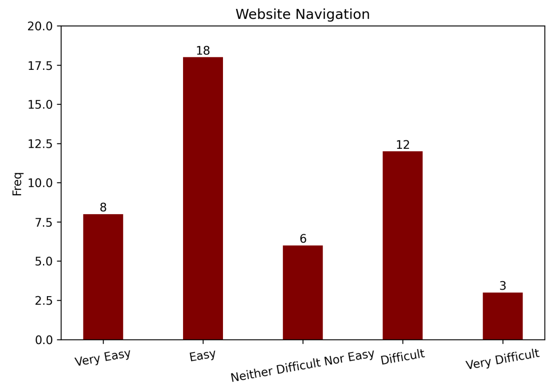


Fig. 4: Participant rating responses on navigating through the website to the tool.

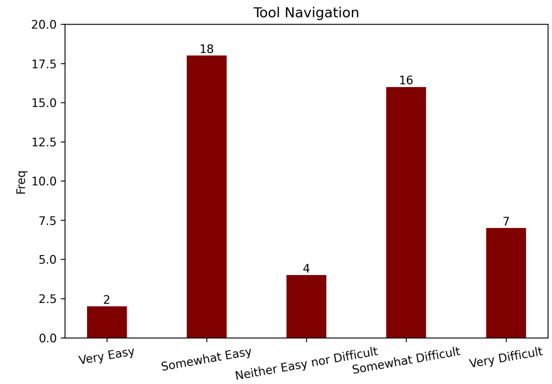


Fig. 6: Participant rating responses on navigation of the robot builder tool.

to the tool. This indicates an area where we need to redesign the navigation and run a direct comparison. In general, we found that most users rated the website navigation experience as very easy for ease of use and intuitiveness (see Figure 5). Note that the counts on both Figures 5 and 7 refer to responses across all features.

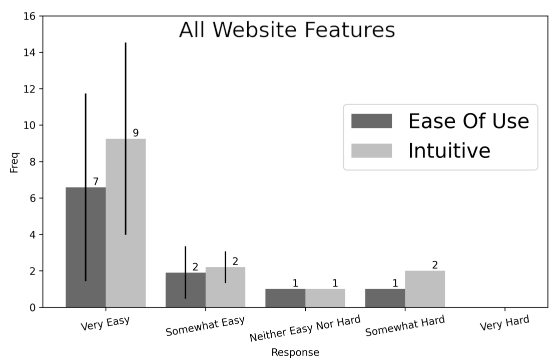


Fig. 5: Average and standard deviation of participant ratings for the ease of use and intuitiveness across all of the website navigation features.

C. Robot Builder Tool Features

Each user started in the tool with a prompt provided through a *challenge card*. When asked what their prompt was for building the robot, 41 participants remembered their prompt, two stated that they were not given one, two stated that they did not remember, and another two claimed that they remembered an option that did not exist.

We then separately assessed the features of the robot-building tool. Although most of the participants did not use all available features, they rated the navigation of the robot building tool more bimodal, rating it as "somewhat easy" but showing a skew towards the "somewhat difficult" to very "difficult" side (see Figure 6). Lastly, users who were unable to submit a robot submitted were asked why. Only one user could not submit a robot, which they stated was due to not being able to hear the tutorial video over the game music.

When we look at the individual results, we see different categories of understanding between the features. Some features, such as the delete part button, are of almost unanimous understanding among all users. This includes having most

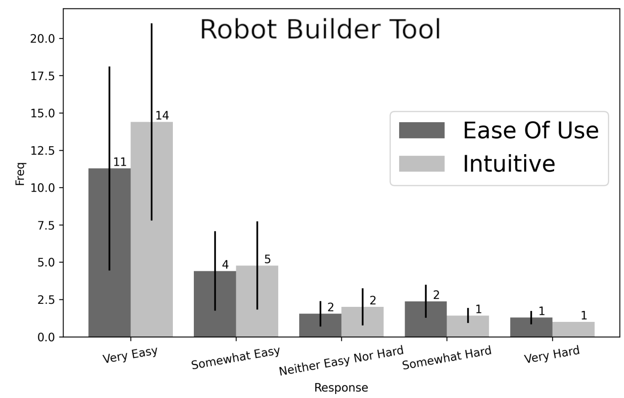


Fig. 7: Average and standard deviation of participant ratings for the ease of use and intuitiveness across all of the robot builder tool features.

of their users respond with a high rating for ease of use, intuitiveness, and usefulness. We identified three groups of characteristic responses that include mostly "very easy", mostly "easy", and mostly unused features. Table IV shows the responses for each characteristic and question. We also found that in general, participants rated the ease of use and intuitiveness of the robot building tool as very easy and easy (see Figure 7).

Lastly, participants were asked if they consider their robot design to be a good match for the prompt they were shown on the challenge card. Figure 8a shows a skew to the left that indicates that they perceived it as a good match, and the majority of participants assessed their own design as somewhat of a match. We did not ask further questions as to why they chose this rating and will re-evaluate this in future study iterations to ensure that the resulting robot database can be populated with good design matches. Figure 8b shows how many parts a participant think they used for their robot design. This shows that under study conditions, participants mostly used between five and 15 parts to create a robot.

D. Music Effectiveness

When asked if users heard the music, 46 of 47 said they had. When asked about the sound effects of the tool, 37 of 47 said they heard them. 15 (31%) of the participants stated that

TABLE IV: Overview of features and their grouped ratings for ease of use, usefulness, and intuitiveness.

Robot Builder	Ease Of Use	Useful	Intuitive
Prompt	very easy	very easy	very easy
Parts Toolbar	very easy	very easy	very easy
Color Slider	very easy	very easy	very easy
Undo	very easy	easy	very easy
Redo	unused	unused	very easy
Delete Part	very easy	very easy	very easy
Duplicate Part	unused	unused	unused
Save	very easy	very easy	very easy
Submit	very easy	very easy	very easy
Menu	unused	unused	unused
Drag	very easy	very easy	very easy
Position	easy	very easy	easy
Rotation	easy	very easy	very easy
Scale	very easy	very easy	very easy
Navigation	**Ease Of Use**	**Useful**	**Intuitive**
Play	very easy	very easy	very easy
Options	unused	unused	unused
Tutorial	very easy	very easy	very easy
Quit	unused	unused	very easy
Website	**Ease Of Use**	**Useful**	**Intuitive**
Home	unused	unused	unused
About	unused	unused	unused
Team	unused	unused	unused
Publications	unused	unused	unused
Sign Up	very easy	very easy	very easy
Login	very easy	very easy	very easy
Light/Dark Mode	unused	unused	unused
Learn More	unused	unused	unused
Log Out	unused	unused	very easy
Build A Bot	very easy	very easy	very easy
Your Bots	unused	unused	unused
Profile	unused	unused	unused

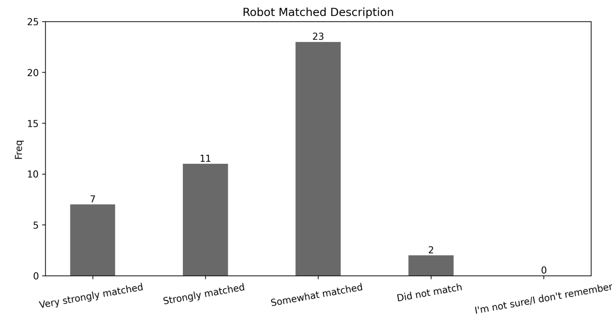
the music itself was distracting. Only 12 people muted the music, seven through the platform menus, and five through their computer's menu. Of the 15 participants who found the music distracting, five stated that it was too loud, two stated that they did not care about it, two reiterated that it was distracting, and the rest did not provide answers.

E. Runtime Environment

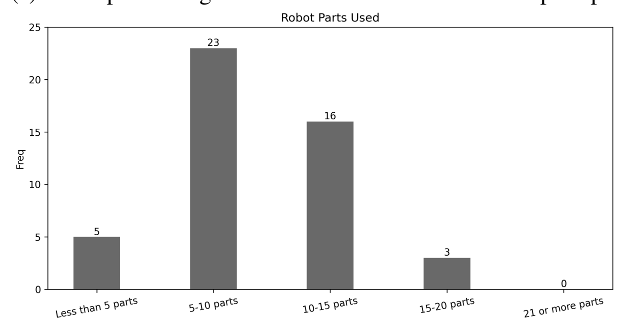
Five out of 47 participants reported experiencing some lag in their system and one person reported that there was too much lag to even complete the task. Computer metrics were collected to further investigate any issues; however, all participants reported that they were testing the platform on sufficient operating systems and workstations.

V. Discussion

The results of our survey indicate that the Build-A-Bot platform is easy to navigate. The assessed version of the website allows users to navigate to the robot designer and successfully build and submit robot designs that correspond to the mental model they create for a given trait. As one of our users puts it, "[the Build-A-Bot platform] is useful for someone with no background of building a robot online [and] go from knowing nothing to completing a bot in no time." However, there are features on the platform that users did not interact with, suggesting that we should deprecate and delete these features or rethink how they are presented, so their usefulness can be better understood. There were also



(a) Participant ratings on how well their robot fits the prompt.



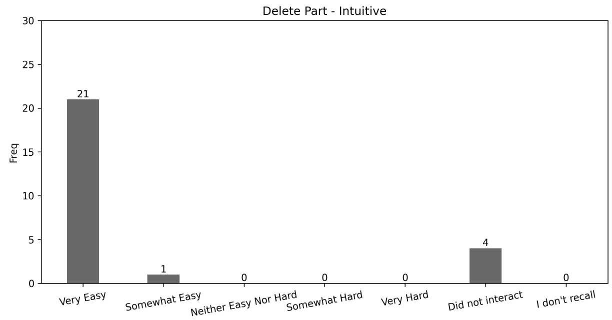
(b) Participant responses on how many parts they used.

Fig. 8: Participant ratings and responses on what they perceived to be accurate about their robot design.

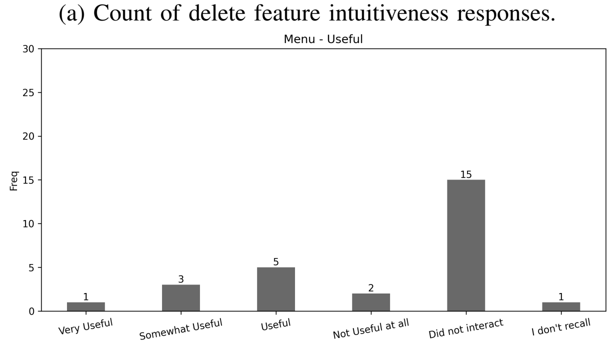
features that users said were difficult to use, suggesting that we need to focus on simplifying the functionality around these features in future iterations.

For our demographics, we are more interested in the identification of patterns in those who find the platform more intuitive or less intuitive. We split our groups by past experience with and without 3D manipulation systems, expecting our users without relevant experience to find the program not as intuitive as experienced users. After performing the chi-square test, we found no significant differences in the ease of use of any feature between those with 3D experience and those without it. Although our platform may appear adjacent to these fields of gaming and 3D manipulations, it seems that effectively creating a robot design on the platform might not require prior experience. Since our experiment design did not require that users build complex designs and our user set was limited, we cannot say for sure that it does not require this background to build other robots within our tool.

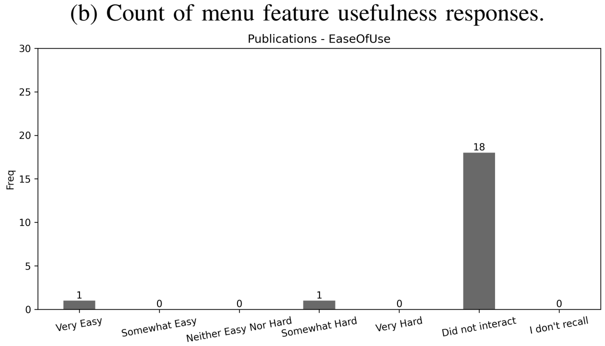
For the platform to support a viable data collection, users must be able to navigate all the way from the homepage to a completed and submitted robot design. Most of the participants were able to complete and submit their robot. This was achieved without any external guidance from us other than the directions provided on the platform homepage and the instruction to design a robot, indicating that the platform is a viable prototype that can be used by the tested population. Users who were unable to complete the task could not do so due to frame-rate lag, and this was not a reflection of any particular feature lacking. We collected data on the user's memory and cpu components; however, none of these correlated with the experience of lag. We continue to



(a) Count of delete feature intuitiveness responses.



(b) Count of menu feature usefulness responses.



(c) Count of publication feature ease of use responses.

Fig. 9: Examples of different response distribution types.

consider lag as a problem and will need to find more targeted questions to identify the underlying issues that lead to lag.

For the tool itself, we can see that some of our features are more unused than anything else, including the options, quit, redo, duplicate part, and menu buttons. Some of these features may be irrelevant to a user, such as being able to mute music from your computer's options rather than our own. We believe this to be the case for quit and menu as well, as they could be avoided, and the user would still be able to complete a full robot. The redo feature's use case is itself rare, as you would have to undo too many times and want your previous work back. The redo tool did have an intuitiveness category of 1, so we believe this to be just a rare use case. Lastly, for the duplicate part button, we saw that very few users actually used the tool. We believe that this feature could certainly use some work or support to ensure that users are aware of this functionality.

The tool also has some features that failed to pass unanimous "Very Easy" categorization. These features include undo, position, and rotational buttons and options. These were listed in the category "Easy" understanding. We interpret this to mean that the participants seemed reluctant to answer "Very Easy" as they might not have immediately understood the feature or how the feature works. Those features will be redesigned and subjected to a hypothesis-driven direct comparison in the next iteration.

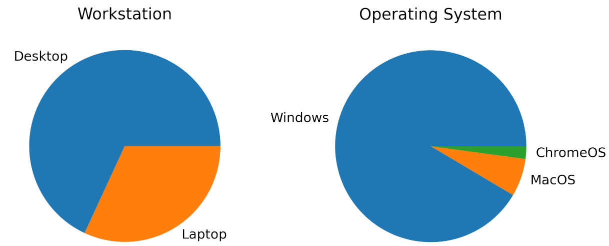


Fig. 10: Workstation and operating system responses.

The website portion of the survey includes many more users who claim that they did not use many of the features. This again makes sense as many of these were not necessary to complete the robot building. The features that are essential for the robot, such as the sign-up, log-in, and build a bot buttons, were unanimously understood under the categorization "Very Easy".

Our assessment showed that 12 of 17 game features are easily understood or very easily understood by most users. The features that did not return mainly positive results include the menu, options, redo, duplicate, and position. Duplicate, options, redo, and menu were unused features by most of the respondents. Some of these, such as options or redo, might not be applicable to every person or robot design process. We believe that it is more important for users who use them to see them as useful. For the duplicate part feature, we believe that this can be a powerful design tool, but is not presented in a way that is universally usable for users. This feature will be re-assessed for ease of use and intuitiveness before the official publication of the platform. It is important to note that this set of users were completely new to the Build-A-Bot interface, and that the assessments could change over time as users become accustomed to the interface. We ultimately conclude that all of the tools implemented are useful to some degree, and that in the following iterations we need to optimize the user experience with the interface.

When assessing sound and music, we found that participants perceived music as too loud. The music also seemed to prevent them from listening to the video tutorial. This is an oversight on our part and an issue that must be addressed. We are evaluating the implementation of a mute button and volume slider, as well as automated features that temporarily pause the music while the tutorial is being played. The music was intended to provide a comfortable experience, and our evaluation showed that we did not get this right. Although we do not believe that we will find a universally enjoyable style of music, we still believe that this music is beneficial to the atmosphere of the game. One limitation of the feedback here is that we did not provide a survey entry for those who wanted to positively comment on the music. We assume that for those who heard the music and did not turn it off, it was at least not detrimental to their robot design process.

Our study had some limitations. For example, we only asked each participant to design one robot. When they did so, it was also their first time interacting with the Build-A-Bot platform. This is a good thing when assessing accessibility within the platform for first-time users but is also a limitation when assessing how all of the website and corresponding platform features function. Users who have recurring interactions with Build-A-Bot will discover new and innovative ways to use the application, and these interactions will provide us with a more detailed picture of the overall accessibility of the Build-A-Bot platform.

In future iterations, we will consider that while a majority of our application interface was considered intuitive and easy to use, there are portions of the website and game interface that were not used or were somewhat difficult to navigate. In future versions of the application, we will focus on simplifying those aspects of our user interface and reworking the presentation of seldom used features to help users better understand their intended function.

VI. Conclusion

In this article, we discuss the effectiveness of the Build-A-Bot robot design platform. We have shown that the design of the robot creation platform and its associated website are considered intuitive and effective by a majority of our survey population. The Build-A-Bot platform successfully provides the ability for users to visualize their ideal representation of a mental model for a robot through a 3D game-like interface.

References

[1] K. S. Haring, K. Watanabe, M. Velonaki, C. C. Tossell, and V. Finomore, "FFAB–The form function attribution bias in human–robot interaction," *IEEE Transactions on Cognitive and Developmental Systems*, vol. 10, no. 4, pp. 843–851, 2018.

[2] E. Phillips, S. Ososky, J. Grove, and F. Jentsch, "From tools to teammates: Toward the development of appropriate mental models for intelligent robots," in *Proceedings of the human factors and ergonomics society annual meeting*, vol. 55, pp. 1491–1495, SAGE Publications Sage CA: Los Angeles, CA, 2011.

[3] S. Nikolaidis and J. Shah, "Human-robot teaming using shared mental models," *ACM/IEEE HRI*, 2012.

[4] C. Brooks and D. Szafir, "Building second-order mental models for human-robot interaction," *arXiv preprint arXiv:1909.06508*, 2019.

[5] J. Banks, "Optimus primed: Media cultivation of robot mental models and social judgments," *Frontiers in Robotics and AI*, vol. 7, p. 62, 2020.

[6] A. Tabrez, M. B. Luebbers, and B. Hayes, "A survey of mental modeling techniques in human–robot teaming," *Current Robotics Reports*, vol. 1, pp. 259–267, 2020.

[7] F. Gervits, D. Thurston, R. Thielstrom, T. Fong, Q. Pham, and M. Scheutz, "Toward genuine robot teammates: Improving human-robot team performance using robot shared mental models.," in *Aamas*, pp. 429–437, 2020.

[8] S. lai Lee, I. Y. man Lau, S. Kiesler, and C.-Y. Chiu, "Human mental models of humanoid robots," in *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, pp. 2767–2772, 2005.

[9] S. Kiesler and J. Goetz, "Mental models of robotic assistants," in *CHI'02 extended abstracts on Human Factors in Computing Systems*, pp. 576–577, 2002.

[10] R. M. Byrne and P. N. Johnson-Laird, "'if'and the problems of conditional reasoning," *Trends in cognitive sciences*, vol. 13, no. 7, pp. 282–287, 2009.

[11] A. Bejarano and T. Williams, "Understanding and influencing user mental models of robot identity," in *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 1149–1151, IEEE, 2022.

[12] J. Sterman and D. Ford, "Expert knowledge elicitation to improve mental and formal models," in *Systems Approach to Learning and Education Into the 21st Century: 15th International System Dynamics Conference: Proceedings*, vol. 1, p. 3, System Dynamics Society, 1997.

[13] E. Pronin, "Perception and misperception of bias in human judgment," *Trends in cognitive sciences*, vol. 11, no. 1, pp. 37–43, 2007.

[14] W. A. Scott, "Cognitive complexity and cognitive flexibility," *Sociometry*, pp. 405–414, 1962.

[15] I. Leite, C. Martinho, and A. Paiva, "Social robots for long-term interaction: a survey," *International Journal of Social Robotics*, vol. 5, no. 2, pp. 291–308, 2013.

[16] L. D. Riek, T.-C. Rabinowitch, B. Chakrabarti, and P. Robinson, "How anthropomorphism affects empathy toward robots," in *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*, pp. 245–246, 2009.

[17] Y. Suzuki, L. Galli, A. Ikeda, S. Itakura, and M. Kitazaki, "Measuring empathy for human and robot hand pain using electroencephalography," *Scientific reports*, vol. 5, no. 1, pp. 1–9, 2015.

[18] S. S. Kwak, Y. Kim, E. Kim, C. Shin, and K. Cho, "What makes people empathize with an emotional robot?: The impact of agency and physical embodiment on human empathy for a robot," in *2013 IEEE RO-MAN*, pp. 180–185, IEEE, 2013.

[19] K. Darling, P. Nandy, and C. Breazeal, "Empathic concern and the effect of stories in human-robot interaction," in *2015 24th IEEE international symposium on robot and human interactive communication (RO-MAN)*, pp. 770–775, IEEE, 2015.

[20] A. M. Rosenthal-von der Pütten, N. C. Krämer, L. Hoffmann, S. Sobieraj, and S. C. Eimler, "An experimental study on emotional reactions towards a robot," *International Journal of Social Robotics*, vol. 5, no. 1, pp. 17–34, 2013.

[21] A. Weiss, J. Igelsböck, M. Tscheligi, A. Bauer, K. Kühnlenz, D. Wollherr, and M. Buss, "Robots asking for directions—the willingness of passers-by to support robots," in *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 23–30, IEEE, 2010.

[22] B. Kühnlenz, S. Sosnowski, M. Buß, D. Wollherr, K. Kühnlenz, and M. Buss, "Increasing helpfulness towards a robot by emotional adaption to the user," *International Journal of Social Robotics*, vol. 5, no. 4, pp. 457–476, 2013.

[23] B. Shneiderman, "The eight golden rules of interface design," 2016.

[24] Microsoft, "Microsoft," 2023.

[25] H. Petrie, A. Savva, and C. Power, "Towards a unified definition of web accessibility," in *Proceedings of the 12th International Web for All Conference*, pp. 1–13, 2015.

[26] B. Shneiderman, "Universal usability," *Communications of the ACM*, vol. 43, no. 5, pp. 84–91, 2000.

[27] F. Winberg and S. O. Hellstrom, "Designing accessible auditory drag and drop," in *Proceedings of the 2003 conference on Universal usability*, pp. 152–153, 2002.

[28] H. S. Vitense, J. A. Jacko, and V. K. Emery, "Multimodal feedback: establishing a performance baseline for improved access by individuals with visual impairments," in *Proceedings of the fifth international ACM conference on Assistive Technologies*, pp. 49–56, 2002.

[29] B. Shneiderman and H. Hochheiser, "Universal usability as a stimulus to advanced interface design," *Behaviour & Information Technology*, vol. 20, no. 5, pp. 367–376, 2001.

[30] L. G. Motti, N. Vigouroux, and P. Gorce, "Improving accessibility of tactile interaction for older users: lowering accuracy requirements to support drag-and-drop interaction," *Procedia Computer Science*, vol. 67, pp. 366–375, 2015.

[31] H. Petrie and N. Bevan, "The evaluation of accessibility, usability, and user experience.," *The universal access handbook*, vol. 1, pp. 1–16, 2009.

[32] MongoDB, "MongoDB: The Developer Data Platform," 2022.

[33] Angular, "Angular," 2022.

[34] H. M. Gray, K. Gray, and D. M. Wegner, "Dimensions of mind perception," *Science*, vol. 315, no. 5812, pp. 619–619, 2007.

[35] T. Sanders and P. Cairns, "Time perception, immersion and music in videogames," pp. 160–167, 2010.