Active Participatory Social Robot Design Using Mind Perception Attributes*

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Abstract. The Build-A-Bot online platform has been developed with the goal to enable active participatory design and broaden the participation in social robot design. The platform is hosted on a webpage to make robot design widely available. Active participatory design is enabled by giving the user the maximum amount of creative freedom in creating their own designs. The platform uses a form of gamification that challenges the user to build robot designs that emulate an experience or agency capability. The overall goal is to create a comprehensive set of robot designs that are related to such an attribute. This data then will allow us to research robot mind perception using Machine Learning and neuroscience methods in the future. This work focuses on the development of the online Build-A-Bot platform and the methodology implemented on the platform.

Keywords: Social Robots · Participatory Design · Robotics · Mind Perception.

1 Introduction

Current social robot designs have many explicit and implicit shortcomings. For example, a robot's appearance might not appropriately reflect the robot's capabilities, leading to miscalibrated human expectations towards the robot [13,26]. A robot may activate different mental models according to context [22] or the robot's surface level cues like its design and appearance [12,36]. A robot's design also often does not reflect a broad spectrum of designs and robot designers due

* This research has been sponsored by the University of Denver under the Professional Research Opportunities for Faculty (PROF) opportunity to Drs. Haring, Kim, and Pittman under grant # 142101-84994 and by the University of Denver under the Faculty Research Funds (FRF) to Drs. Haring and Pittman under grant # 142101-84694.

to the under-representation of minorities in Computer Science and Engineering fields [18]. Appropriately designed robots can limit miscalibrated user expectations and misuse of robots, potentially improving the lives of many by providing social, physical, and emotional support. Such robots are the future of education, work, health care, elderly care, and could help maintain cognitive and physical health [4,8]. Robots are complex machines that unite advanced technologies in a robot body and their behaviors should be social enough to engage humans in the task at hand. However, the initial challenge that every social robot needs to overcome is posed by its own design and appearance. Cognitively, the robot design should reflect the robot's capabilities as those will shape the user's expectation, [13] which will in turn shape its acceptance by the user (Technology Acceptance Model (TAM), [35]). Socially [6], the robot's design should express the robot's social capabilities and shape user expectations towards the modality of the social interaction. Lastly, the robot's design also needs to house all the necessary technology that makes a robot functional, both computationally and mechanically, which is often referred to as "form follows function" [13,34]. Given current robot designs, it seems to be the case that robots are often designed for their function first and then their form is adapted given the function. This research reverses this paradigm. In our approach, we start with (human) mental states [11] and then ask users to design robots according to these mental states in an active participation robot design task.

1.1 Literature

It is unclear what a social robot design needs to entail to successfully interact with children, elderly, the workforce, or as in-home assistance. We lack a systematic and comprehensive understanding of the range, variety, and relationships among constituent features of anthropomorphic robots [27]. While recent research has approached this challenge by evaluating existing robot designs through explicit (e.g., self-reported experiences) and implicit [7] methods, using existing robot designs exclusively introduces a designer's bias, the unconscious patterns designers use while they're creating something, of what a social robot for a specific purpose should look like. A different approach that could mitigate this bias is participatory robot design. While a participatory design approach might not completely eliminate bias in robot design, when utilized on a large scale with hundreds of robot designs, the increased number of designs could mitigate individual biases. This method could also significantly broaden participation in robotics and robot design [28], and therefore help mitigate biases that might occur when homogeneous populations direct robot designs.

Participatory design (PD) can either be active or passive. It seems that "passive participation" is more common in current practice [29]. Passive participation usually takes the form of information obtained through questionnaires and interviews, meaning this explicit data is what users report about themselves. While this level of involvement is preferred to complete exclusion from the design process, it does not provide the same level of stakeholder influence as an active approach where users participate in the design process [32]. Active involvement is what differentiates participatory design from traditional user-centered design approaches as it allows the user to timely influence their future experience with the product [32]. Active participatory design has been explored in several fields, including social robotics. For example, children diagnosed with autism were asked to build a collage that represents a design for a social robot [29]. The study found that the children expressed broad opinions on the morphology of their final robot design, and combined features in ways that did not exist in current robot designs [29]. Furthermore, the study found that the children showed motivation during the building activity, including "an increase in communication using words and non-verbal signs to express enthusiasm regarding their final sketch" [29]. This increase in creativity (i.e., creating designs that do not yet exist) and engagement in the robot design process are benefits of participatory design we seek to implement on our platform. Additionally, we will be soliciting robot designs from a broad spectrum of people in regards to age group, neurodiversity, socioeconomic background, and cultural background. In order to take advantage of these potential benefits of active participatory design and to facilitate the broadening of participation in robot design, we have defined five main requirements for our platform. The platform must be: (1) easy to navigate; (2) facilitative of the robot design process; (3) accessible via the world wide web; (4) accessible for users of a broad age group (e.g., elementary school age groups to elderly); and (5) accessible for neurodiverse users. To achieve this, the platform will need to, at minimum, be online on a web page, utilize minimal text and more icons and images, and allow for user creativity and intuitive assembly of parts that form a robot. Additionally, the Build-A-Bot platform will benefit from employing universal design principles, making it usable by people with the widest possible range of abilities [14]. On the Build-A-Bot platform we allow users to combine robot parts in 3D space, similar to a character creator in a game, to see what a robot of their own design might look like. The user is fully in control of their design and our goal is to avoid guiding the user towards any particular robot design.

In addition to the benefits of active participatory design, there seems to be evidence that robot designers express a relationship with their creations beyond the initial increased engagement in the design process [29]. This might particularly be the case when the robots created on the Build-A-Bot platform are 3D-printed. Research shows that human-robot relationships can show feelings and actions resembling attachment [17]. Other examples of relationships with robots that form beyond typical relationships with objects are the naming of robot vacuums [10] or the hosting of robot funerals after a military robot is no longer serviceable [5]. While there is some evidence that people create attachments to robots in general, we are also interested in how a human-robot relationship changes when the user is involved in extensive design, engineering, and testing phases. In this context, it has been found that that people also seem to feel sad when they have to destroy their LEGO™ robot creation [16]. The initial version of our Build-A-Bot platform focuses on the visual design of a robot.

Based on initial user tests, we estimate that a robot design could be created in around 20 minutes, which might not be enough time to activate feelings that resemble attachment. However, it could be the case that users enjoy creating a robot on a behavioral level or evoke an emotional response on the visceral level both in the creator and an observer of the design [24]. Additionally, there currently are no studies that have evaluated the relationship of virtual robot and their designers and the changes in that relationship when the robot creations take on a physical form. To enable an evaluation of this research question, an additional requirement to the platform is that (6) the robot parts in the platform need to be exportable as 3D-printable files that could then be assembled into a physical robot.

A secondary result that we hope to achieve with this online platform is to broaden participation in robotics and robot design. In the long run, the robot designs created on this platform will inform a Machine Learning model that uses the robot designs to learn, as well as make an evaluation of how design influences the mind perception in robots [15,42,20]. An important, but not sufficient, contribution to mitigate bias in Machine Learning is to create less biased data sets. This can be achieved if this platform is able to reach a broad spectrum of users that become robot designers, especially those that are traditionally not represented in the current robot design communities. In addition, for participatory design, it has been found that a third space ensures the greatest chances at creative solution finding [23]. Virtual robot design takes robot design from the researcher's lab and away from the user's designated work space by creating a third space online. In order to create a virtual third space, our last requirement is that (7) the platform needs to enable custom user settings and platform-specific sounds and music to establish an atmosphere and feeling of being in a third space [31,25].

2 Methodology

To address the seven stated requirements that will enable us to achieve the short and long-term goals of the Build-A-Bot platform, we made several decisions on what software to use in the development of the online platform and on how to set up the platform to be able to apply Machine Learning models and neuroscience evaluations of robot designs in the future.

On the technical side, we used Unity [43], Maya [19,37,38], Blender [19], WebGL [40], Neo4j [3], Angular [1] and MongoDB [2]. This combination allowed us to create a web page where a robot can be assembled from individual parts via drag and drop. It also allows us to store the actions taken by users while creating the robot design in MongoDB, a graph representation of the parts used in Neo4j, and a screenshot of the robot design. Together with the target mind perception attributes for each design, this data will be used to train Machine Learning models that focus on feature extraction and eventually might be able to generate new robot designs. We used insights from social psychology and existing mind perception research to create a "challenge card" (see Figure 1).

The challenge card prompts the user to create a robot that possesses a certain experience or agency attribute (e.g., ability to memorize or plan, the ability to experience joy or fear [11]). The challenge card also asks the user to use a minimum amount (e.g., four) of robot parts. This serves two purposes in our methodology: first, it gamifies the approach to robot design and gives the user varying challenges and engaging them to create several designs [44]; second, it enables us to use the robot designs for further analysis based on neuroscientific methods (i.e., fNIRS) where it will be necessary to know the complexity of a design (i.e., number of parts). For the design and accessibility, we used Figma [9] as a prototyping tool to evaluate the layout and navigation of the platform before implementing it on the webpage and in the Unity game. We also used existing research on how to best represent mind perception attributes through icons [33] to broaden participation to users that are not literate or have reading difficulties. Where no iconography representation existed, we created a small set of icons.

2.1 Technology

To enable the requirements around facilitating robot design processes, broad access, and ease of navigation we decided to use the Unity game engine [41]. Using Unity allowed us to design robots similar to how one would create their own characters in a video game. Unity also offers flexibility, extensive documentation, and existing implementations of character creation interfaces [21] from which we based our new robot design interface. One example of a character creation interface that we initially investigated was the Unity Multipurpose Avatar (UMA) package [39]. However, UMA would not allow us to meet our requirements as it focused on humanoid models, and did not allow the creation of more biomimetic or non-biomimetic robots. This prevented a crucial feature in our requirements: the ability to combine robot parts in any manner the user chooses.

Unity also provides support for WebGL, which allows us to run the Build-A-Bot platform directly in a web browser [40]. On the 3D modeling side, we initially only used Autodesk Maya for the creation of the robot parts as it has faster rendering times [37] and offers more details in the modeling [38] than Blender which is desired to maximize robot design choices. However, we have since found that for our purpose, Blender delivers sufficient 3D parts. We also found Blender to be more approachable for new members of our team, which led to a transition to using both Maya and Blender. Both Maya and Blender allow us to provide a wide range of 3D-models for robot parts. This in turn empowers users of our platform to build a wide range of creative robot designs. Our platform also strives to maximize the user's autonomy of their robot design, thus fulfilling our requirements for active participatory design.

2.2 Design Approach

In order to fulfill our requirement of ease of use and navigation, our platform went through several design iterations using rapid prototyping. We used Figma [9] to prototype design ideas. In addition, we are continuously implementing feedback on the navigation of the platform from quality assurance testing as we publish new updates. This includes, for example, the ease of use of the scaling and rotation features for robot parts in the game, the coloring of different robot parts, identifying functionalities that would make the robot design more straightforward, and finding bugs (e.g., some of the 3D models with a high polygon count can freeze the game). To decrease potential biases, we aimed to increase the number of available 3D models and added scaling features to the Unity platform. Having more variety of available parts and the ability to modify those parts allows us to provide the user with more space to be creative. For example, a sphere could be used for a robot's head or be a body part of a caterpillar-like robot. Once a part is selected users have the ability to transform the scale, position, rotation, and color of the part and to attach other parts to it (see Figure 3). The Unity game is not programmed to take into account physical or real-world constraints. We hypothesize that this removes limitations to a user's creativity by imposing as little constraints as possible.

2.3 Robot Mind Perception Integration

Before starting the design of a new robot the user is given a target mind perception attribute to explore and target with their design. The user is presented with this mind perception attribute in what we call a "challenge card" (see Figure 1). This challenge card additionally contains a set of requirements for the robot design. These requirements include things like a minimum number of parts, or a minimum number of parts of a specific type. This allows us to gather a broad range of designs with a particular set of requirements and/or targeting a particular mind perception attribute. These subsets of designs can then be analyzed for patterns that may or may not be present in other design subsets. While the user is building their robot design, we keep track of the different actions that the user takes and the different robot parts that they choose to use. For example, we track the order that the parts were used in, any changes to the size, position, scale, rotation, and color of the part, and any parts that the user chooses to delete. This data is important as we want to not only know what parts the user chose when targeting a certain mind perception attribute, but also the sequence of decisions they made when choosing and modifying those parts. As an example, we hypothesise that if a user were given a target of building a robot that was capable of feeling hunger, they may choose to use a robot with a humanoid torso, and possibly a large stomach area. If we found that users that were given this target attribute were incorporating design elements such as this, it may indicate a pattern in the human perception of a robot with that target attribute.

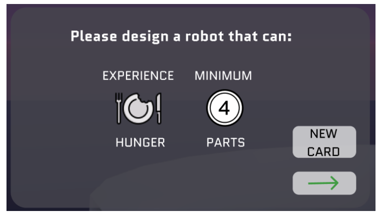


Fig. 1: An example of a Challenge Card asking the user to create a robot that is able to experience hunger and is composed of a minimum of four parts.

3 Results

3.1 Platform Implementation

To facilitate the seven requirements we identified, we implemented the Build-A-Bot platform as described in the Methodology section (see section 2) as web-accessible 3D game.

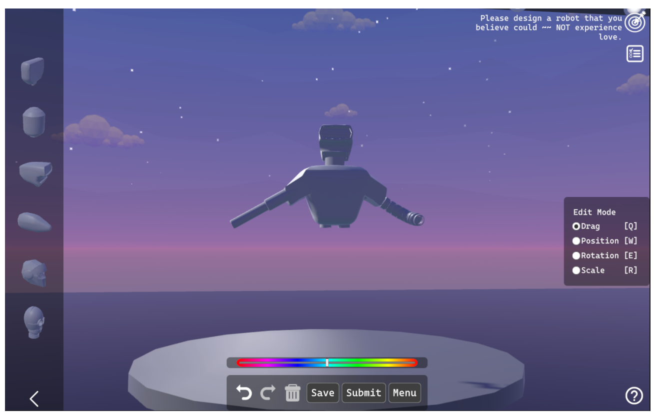
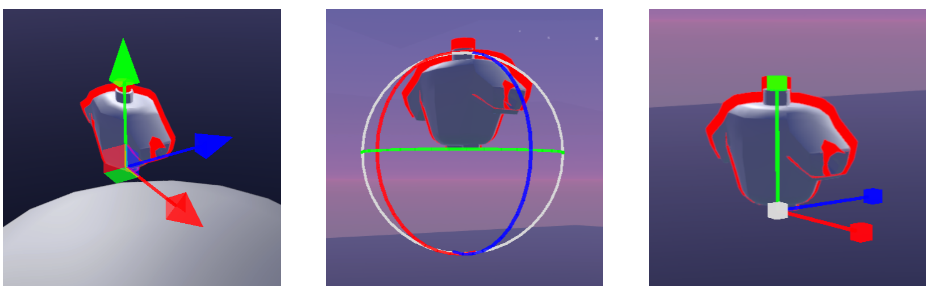


Fig. 2: The user interface of the Build-A-Bot robot design platform. On the left are the 3D robot parts than can be used via drag and drop. The individual parts attach to each other to create a robot design. At the bottom are different actions that the user can take like undo, redo, delete a part, color a part or several parts, save the robot for later, or submit the final robot design. On the right as other actions like dragging, positioning, rotating, or scaling a part or several parts at once. On the top right, the current challenge card is being displayed.

In addition to making the game accessible to a broad audience, one of our main goals with the design of our platform was to make it as intuitive to use as possible. With this in mind, we iterated through several different user interface designs for the platform. In the end, we chose to implement a design in Unity that makes significant use of icons for all of the aspects of the interface. This helps us achieve the goal of making the platform easy to use for many different groups, such as those who do not speak English or those that cannot read, such as children. The current iteration of the UI design for the Unity platform can be seen in Fig. 2. While there is still some text used in the current iteration, we are working to replace this with additional in future iterations.

In our Unity implementation, we also worked to ensure that the flow of the application is intuitive for a new user who likely will not have previous experience manipulating objects in a virtual 3D space. To do this, we adopted a standard set of methods for transforming the 3D parts in our game. The different methods of transforming the 3D parts can be seen in Fig. 3. In addition to these three options, users can also drag a part to move it, and can change the colors of the different parts they are using. With these tools, the user can modify the part in whatever way they please. We do not want to tie users to using the existing parts without modification, as that could limit user creativity. Our goal is for users to be able to design exactly the robot they believe best meets the mind perception attribute they are targeting.



(a) Position (b) Rotation (c) Scale

Fig. 3: The three different methods of transforming 3D robot parts in the Build-A-Bot design platform.

3.2 Music and Sound Effects

We are expecting that users might spend longer amounts of time in the game and explore the possibilities of creative robot design. In order to create an atmosphere, many games employ music and effects [25]. We worked with a sound designer to create music that plays while users play the game. Classical music has shown to be beneficial for cognition and creativity [31] and the goal of the background music in our game is to emulate this creativity. Users can disable the music in case they are in an environment where it is not appropriate to play music. We also employed sound effects that along with visual effects to confirm that a certain action has been executed. For example, when two parts of a robot are attached to each other, they "snap" together visually by showing sparks and audibly by making a snap sound. The sounds and music can be explored on the current online prototype when playing the game on the Build-A-Bot webpage `www.dubuildabot.com`.

3.3 Enabling Active Participatory Design

We designed the Build-A-Bot platform so that users can create designs as freely as possible. For example, if a user does not like the challenge card presented, they can switch to another challenge card. Additionally, the platform does not impose any constraints on the order, size, or color of robot parts used, or how the parts are being assembled. There also are no real-world physical constraints, meaning the robots designed do not need to be functional in any way in order to be a valid robot design submitted to our database. We hope this maximizes creativity and minimizes the limits of possible design in order to create a more comprehensive robot design database. The goal with the design freedom we provide is to enable the active participatory design that is a key goal of our platform. By allowing users to create their own experience with the platform, we hope to increase user engagement and enjoyment with the platform.

4 Discussion

Designing, testing, and building social robots requires significant resources and time. One way to improve this process and add significantly more knowledge into how social robots can be designed is to enable access to large amounts of data about such robots. However, such data is not currently available. One of the goals of the Build-A-Bot platform is to create this large amount of data on the design of potentially social robots and give insights into how such a robot is perceived. This would then likely enable robot designers to start a social robot design with a perception goal in mind and design robots for a specific purpose. It is important for the large dataset we create to be comprehensive and reflect a broad spectrum of robot designs. Our approach of using active participatory design helps achieve this, as it can help increase knowledge and user satisfaction of a robot's design, allowing a broader range of designs to be created. It is also expected that when such data is evaluated and machine learning models are developed, having a more comprehensive database that is populated by a broad spectrum of users is an important first step towards mitigating biases in robot design. For example, while physical robot design is often limited to companies that have large resources or to engineering oriented universities or schools, our platform is accessible to users of a much wider range of age, origin, location, literacy, and socioeconomic background as only an internet connection and a browser is required to create a robot design. Our platform therefore has the potential to increase accessibility to robot design, simplify the design process, and with that, increase the number and diversity of robots designs and information about each design.

4.1 Future Directions

Systematic User Evaluation We ran a short quality assurance survey with online participants that showed that the current platform version indeed enables users to build a robot. It also highlighted some areas of improvement for the platform usability and navigation. To ensure that we deliver according to our requirements, we will run a systematic user evaluation study expanding on the results of the preliminary survey. The experimental design of the study will test each of the seven requirements. In addition, we will investigate the icons we designed in a separate study (IRB approval pending). Additional user evaluation includes a comparison to real-world robot designs with the same prompts and using 3D-printed and Lego building blocks and we anticipate the organization of a workshop around the evaluation, usability, and future directions of this platform by the social robotics and designer community.

Machine Learning One goal of the Build-a-Bot project is to analyze different designs, and the perception of those designs, to better facilitate social robotics. In order to evaluate new robot designs, determine what factors elicit a certain perception of the robot, predict the perception of novel (currently not existing) robot designs, and automatically generate new robot designs, we are developing the Build-A-Bot platform in a way that facilitates Machine Learning, using the active participatory design submissions to the platform as the basis for training our machine learning models. For this, we collect various data points from our platform. Our first metric of interest is a screenshot of the robot design from a fixed perspective. These images are used to train a Convolutional Neural Network (CNN) with the goal of determining what it means to look like a specified category of social robot. With enough training data from the platform, we may also be able to use these images to generate new images of a robot, providing new appropriate robot designs for a category. Another metric we are collecting is data on the steps that the user takes while building their robot design. Each step the user takes (e.g., drag, resize, undo, delete), and in what order those steps are taken, is recorded. While this may not directly contribute to our machine learning models, it provides a standalone dataset that we can process to find relationships between robot designs in a given category. We expect that this can lead to insights on how people design robots, if there is a common ordering to how users approach designing a robot, and if there are specific steps or information we can identify for specific robot categories. Lastly, we also are recording the all the parts that make up a final robot design and their corresponding locations, scales, colors, and properties. These properties associated with each part will then be combined together to create a graph representation of the submitted design. The parts themselves will represent the nodes in the graph, and the relationships between parts, such as distance, will be the edges between nodes. In order to better understand the impact these relationships between parts have on how a design is perceived, we will be turning to Graph Machine Learning [30] techniques to train a deep-learning model that can be used as an alternative classification method to our CNN trained on screenshots of the robot. We plan to compare the accuracy of both methods to determine with machine-learning approach, or if a combination of both approaches, is a better use-case for this domain.

Model Validation with Novel Metrics Another goal is to evaluate robot designs and the associated mind perception of robots through independent measurements. While Machine Learning can be very powerful, we decided that in order to validate and verify our models, an independent measure will add immense value to the body of knowledge of robot design, neuroscience, novel metrics for HRI, and verification of Machine Learning models. We decided to use functional near-infrared spectroscopy (fNIRS), an optical brain monitoring technique that uses near-infrared light to estimate cortical hemodynamic activity which occurs in response to neural activity. fNIRS is non-invasive, portable, comparatively cost-effective, and has good resolution to evaluate human brain regions that are associated with a Theory of Mind (ToM) [15]. fNIRS has shown that it can detect human empathy, a mechanism that is closely associated with a human's Theory of Mind [15]. We will begin our evaluation with a proof of concept demonstrating that people experience empathy when seeing a robot designed with the ability to feel pain and a pain stimuli, and compare it to the brain activation seeing a human and a pain stimuli. We expect to find that human brain activation will show that humans feel empathy for robots, however at a lower salience than for other humans.

4.2 Limitations

The biggest limitation introduced when making robot designs possible on a web-accessible platform like Build-A-Bot is that all robot designs are virtual. Virtual robot designs and their perceptions do not necessarily translate directly how a robot is being perceived in the real world. While we cannot eliminate this limitation completely due to our goal to create a large amount of data on robot designs and broadening participation in robot design, we are mitigating this limitation in three ways: (1) all 3D robot parts can be exported as .stl files and 3D printed. This enables us to print and assemble select robot designs and evaluate them further; (2) all robot parts are three-dimensional due to the implementation in Unity – while this does not enable a real-world comparison, it is considered a improvement from having two-dimensional designs; and (3) we plan to re-create a small subsection of this evaluation in the real world. For that, we create similar challenge cards but have participants assemble robot designs with LEGO™ builds to evaluate design structures outside of the parts we provide in the game, as well as have participants assemble robot designs with 3D printed parts from the game. This allows us to compare the virtual designs and the real-world designs and gather further information on the reliability and validity of the robot designs made on the virtual platform.

5 Conclusion

The goal of the Build-A-Bot platform is to provide a tool to assemble novel robot designs. The robot designs are associated with a mind perception attribute they should be designed for, but otherwise are left to the creativity of the user. It is expected that the platform will successfully enable a broad participation in robot design due to its usability and accessibility, and enable active participatory robot design due to the methodology we implemented with our technical approach. We believe that, once Build-A-Bot has fully launched, we will show that the platform indeed enables users to create creative and novel robotic designs, and enables a broad participation from a diverse set of users. Once we have gathered an initial set of robot designs, we can then show in the next steps that Machine Learning models with bias mitigation and independent neuroscience measures will lead to an in-depth understanding of social robot design and contribute important knowledge to the area of robot mind perception.

Acknowledgment We are grateful to our students Abdul Ayad, Mike Blanding, Marley Bogran, Madeline Bohn, William Bohrmann, Gillian Ehman, Josh Ellis, Angel Fernandes, Tanner Francis, Sergio Gonzales, Elizabeth Gutierrez-Gutierrez, Ulises A. Heredia Trinidad, Beatriz Hernandez, Esabella Irby, Henry Jaffray, Izzy Johnson, Braden Kelsey, Yahir Luevano-Estrada, Nicholas Ninos, Sneha Patil, Max Peterson, Yasmin Raz, Hector Armando Rodriguez, Ashley Sanchez, Grace Strasheim, Raghav Thapa, Maisey Toczek, and Ralph Vrooman for their work on DU Build-A-Bot.

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