Optimizing Physical Design for Socially Desirable Robots in the Classroom: A Study with Children

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***Abstract*—The use of social robots in early childhood education has significantly increased in recent times, due to their ease of use and access by educational systems. As such, children are in increasing contact and actively interacting with these robots. It is paramount that these robots are designed to effectively communicate and interact with children in an appropriate manner, and to make them feel comfortable and at ease. The appearance of the robot is the most obvious aspect that must be designed in a suitable manner. In this paper, we discuss and analyze what appearance makes a social robot most comfortable for children and humans in general. Furthermore, we examine the types of physical design choices which result in the most effective learning for young children in the classroom environment. A standard model of a robot, with modular components, is to be constructed to form a template for design choices. Then, these modular components will be swapped out to create combinations of robot designs, which will then interact with children. These children will be tested and questioned as to the robot's effectiveness in a classroom setting. These will be implemented in the Webots simulator to mimic the experiment setup. This study will give a greater understanding of what design elements are most suitable for children in an educational setting, and how to design social robots for said purposes.**

***Index Terms*—Human-Robot Interaction, Education, Children, Classroom, Appearance, Physical Design**

I. Introduction

In recent years, technology has become increasingly integrated into the classroom as an educational tool; robots in particular hold great potential in supporting young children's learning in many areas, such as science, technology, engineering, and mathematics (STEM) education, language learning, and social skills development. They are especially valuable as shrinking budgets and increasing class sizes necessitate the need for more teaching assistants [1]. As they continue to be more integrated into education, it is paramount to ensure that these robots are designed to be socially desirable and engaging for children. Robots are becoming increasingly commonplace in schools for educational purposes, and playtime in general. Indeed, it was found that the use of robots in childhood education ”encourages interactive learning, making children more engaged in their learning activities [2].”

One important aspect of robot design, particularly in the context of human-robot interaction (HRI), is the physical design of the robot. It plays a critical role in shaping people's interactions with, and perceptions about robots, especially in social contexts, such as attitudes about robots' intelligence, trustworthiness, and approachability. Indeed, Vernon et al. suggest that humans form impressions of each other within 100 ms, which may be expected to be similar for humanoid robots [3]. They start forming more complex opinions and beliefs about one another from 30-120 seconds into the interaction [4]. This is especially pertinent in the context of children, as since they lack more advanced cognitive reasoning, they are more likely to use appearance to judge how truthful a statement is, especially as it relates to faces [5].

The function is also a key attribute in determining a robot's appearance. Since this robot will be used for educational purposes in a classroom setting for children, it will require specific design elements for this task. A social robot will need to be purpose-built and designed with the tools to carry out these required specifications to meet its purpose.

II. Related Work

Research suggests that humans and children preferred robots with a more anthropomorphic appearance, that is more of a human-like look [6]. Robots designed to resemble humans, with arms, legs, and a head, are perceived as more friendly, approachable, and intelligent [7]. This is likely because humans are more responsive, and more readily connect with emotional, and appearances they are more familiar with. Animal-like appearances exhibit a similar effect, as they were also found to be more readily accepted by humans [4]. Indeed, humans interacted less socially with mechanical-looking robots, instead treating them more subserviently. Humans also regarded them as less competent, with lesser abilities and poor reliability compared to more anthropomorphic robots [8]. This expands to the emotional realm as well, as more anthropomorphic or zoomorphic robots may be perceived as more comforting as they likely use pre-existing and well-known biological cues that are familiar to people, e.g. gaze patterns [4].

Consequently, there are several design philosophies when it comes to designing a robot. The most important aspect of designing a likeable social robot is familiarity and approachability to things humans know and trust. As most people are familiar with other humans and animals, these are the typical templates or archetypes for robot design. However, it should be noted that if someone is not familiar with one of these, then this likeability due to familiarity dissipates. For instance, robots based on dogs and cats are regularly used and perceived as positive, whereas people show more hesitation towards tigers and seals as they are less familiar with them [4].

However, Mori suggested that there exists a phenomenon called the ”uncanny valley.” It postulates that as robots and other artificial beings become more human-like in appearance, people's perception of them becomes more positive and empathetic. However, there exists a point at which the robots become so human-like that the response becomes negative and eerie [9]. This effect is also seen in animal-like robots, but interestingly, the effects are less drastic with zoomorphic robots than anthropomorphic robots; this is likely because human-pet relationships tend to be simpler and therefore expectations of what is ”realistic” is lower [4]. Experiments were done to show that children generally also exhibit the same uncanny valley effect as adults, but robots in motion performing some activity can mitigate the effects of the uncanny valley for children [6]. Nevertheless, the uncanny valley is still a significant effect that must be considered for any effective social robot design for children.

The task a robot is designed to complete also affects human perceptions of its appearance. People more readily trust robots whose tasks match their appearances, i.e. those with an appropriate social role matching their appearance. for instance, social therapy robots are more effective when they are more human-like, as emulate a therapist or social agent who specializes in therapy [10].

However, the impact of robot appearance on people's perception of them does vary across cultures. For example, participants from China and Japan had more positive emotional responses to robots with a more neutral expression, whereas those from the United States had more positive emotional responses to robots with a smiling expression [11].

However, there are also ethical risks in creating robots that too similarly resemble humans. The over-anthropomorphization of these robots may lead to easier emotional manipulation and forming of human relationships with these robots, subsequently resulting in negative behaviours. In more extreme scenarios, there are fears that robot relationships will replace those with humans, which will result in less human interaction with friends, families, and other people [10]. Furthermore, as human perceptions of robots are ultimately based on human opinions, beliefs, and biases, caution must be used such that the physical design of social robots does not reinforce any possible sexual, racial, religious, or other bias that humans have [10].

Children follow most of the same psychological beliefs and influence towards social robots as fully human adults. They likewise preferred robots with anthropomorphic characteristics. Furthermore, it has been suggested that younger people are more comfortable with robots, as they have seen them more readily in popular media and culture [6], [12]. However, children also find robots modelled on toys to be friendly and approachable; indeed, this may even be the appearance that children most preferred [13]. They are more comfortable with inanimate objects having lifelike qualities, e.g. speech and emotions [6]. Smaller robots are also preferred by children, as they seem more relatable and less larger-than-life [1]. However, Robins et al. found that children with autism initially preferred a more robotic social robot, when compared to a more realistic doll robot; but over time, these preferences were negligible and they became accustomed to both [14].

The current most popular robot in use by schools and other educational intuitions is the Nao, a bipedal humanoid robot standing 58 cm in height and equipped with various sensors, speakers, microphones, and cameras integrated into its body (Fig. 1) [1]. The humanoid features, e.g. head, eyes, mouth, legs, and arms, in a human-like proportioned manner all contribute to its physical sociability. For educational purposes, this form is even more significant, as children look up to human teachers and adults as educational role models; therefore the robot should match this rough appearance. Its size also makes it more approachable, especially so when it comes to children who are also smaller [1].

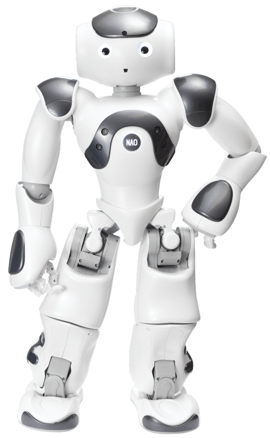

Fig. 1. The Nao social robot, developed by Softbank. Its wide availability, humanoid appearance, and price point have made is widely popular throughout various educational, health, and companies. Note the many humanoid features, e.g. head, eyes, mouth, legs, and arms all proportioned in a human-like manner [1].

Social robots as teachers have shown great promise in tackling the unique challenges of children with special needs such as autism. As children with autism have degrees of impaired social interaction, communication, and imagination, they may find it difficult to understand the complex nuances of human interaction. Therefore, social robots have been used, with their simplified gestures and appearances, to teach and interact with these children to enhance their academic and social skills [14].

III. Research Questions

Current works have focused extensively on what ”general appearance” is more appropriate for humans and children, that is, humanoid vs. non-humanoid with sometimes some spectrum of options in between. Most research has reached a broad consensus that a more anthropomorphic appearance to a social robot is preferable. However, there is little to no research being done on what specific elements of an anthropomorphic robot’s appearance are most conductive to children. Furthermore, there are few studies evaluating the effectiveness of a robot in teaching educational materials, e.g. facts-based learning; they have instead focused more on the social perception of the robot itself.

We seek to understand what specific social robot design elements will lead to the greatest understanding and retention of knowledge by children when taught by the said robot. We will also further analyze what combination of design elements leads to the best outcome, and attempt to characterize them. Thus, we will design said robot in Webots and investigate the following questions:

Question 1: How can a robot’s appearance be designed such that it is comfortable for children in an educational setting?

As the robot is meant to be used by children in an educational setting, they must be comfortable with it. Subsequently, the time it takes for children to feel comfortable around the robot should be minimized. Furthermore, we also want to categorize how the children feel toward the robot in a non-learning setting. That is, how comfortable do they feel around it? Afterwards, we move on to the educational intent and function of the robot and ask:

Question 2: How can a robot’s appearance be designed such that it results in the best learning outcomes for student users?

The primary purpose of an educational social robot is to educate and teach children, and it must be able to do so effectively. We want to know how well combinations of physical design choices affect that teaching ability and also compare it to a human. The specifics of the experiment and study are discussed below.

IV. Experiment

A. Method

1) Setting: To further research our questions, a study will be done using the online simulator Webots, which is an open-source and multi-platform program used to simulate robots that is widely used in academia. It also has many built-in robots such as the aforementioned Nao. In the experiment, children will be asked to interact one-on-one with the robot and their responses will be recorded. This will be done in a classroom setting to simulate a real-life use case of the robot. Then, parts of the robots will be swapped out to create combinations of robot designs, which will then interact with children, with the latter's responses recorded again. In the end, we should have a comprehensive understanding of what design decisions create the most optimal social robot for childhood education.

We will vary three physical parameters for the humanoid robots, those being facial level of anthropomorphization, size, and torso design. The level of anthropomorphization describes how human-like the robot is. Two levels are to be analyzed, mechanical, which will generate a facial appearance similar to the Nao robot (Fig. 1), and humanoid, which will be based on a barbie doll. The size or height will vary in 3 stages, small (20-30cm), medium (45-60cm), and large (80cm+). These are given as ranges due to the need to be flexible when designing the robots as sensor considerations may make it impossible to have all models of robots be the same size. Finally, the torso design outlines the appearance of the robot below the torso. There are two designs for this, a legged and a non-legged variant. The former will include legs, whereas the latter will merely have some sort of base. Thus, we will have a 2x3x2 factorial design experiment.

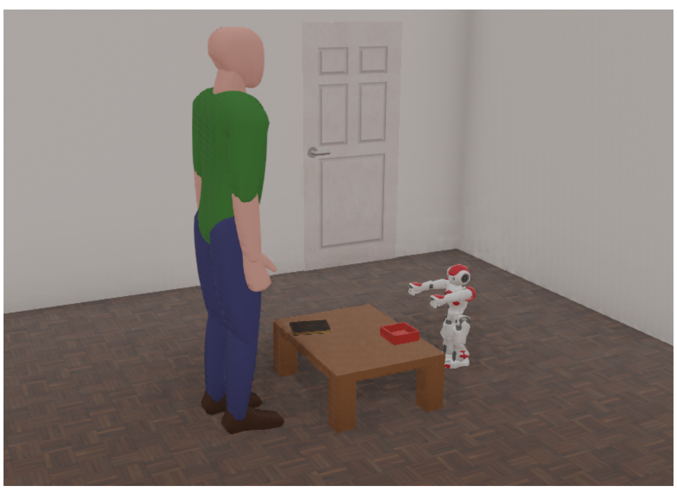

Fig. 2. An example trial with a child across from a robot in an classroom environment. Certain physical aspects will be altered throughout various trials.

2) Participants: For the experiment, we are planning on recruiting elementary school-aged children, i.e. 6-13 years old. They should ideally be from the same school to ensure that they have the same base level of knowledge as compared to each other. We also want an equal distribution of male and female-identifying children such that the results are not biased by gender; this will also make it easier to analyze any potential differences in the genders later. Thus, we are looking for around 60 participants such that each robot combination will have 5 participants. They will be given a quick introduction about the role of the robot and the fact that it is to be used for educational purposes. The students will also be given a simple aptitude test about the topics to be discussed with the robots to ensure a baseline level of knowledge. All interactions between the participant children and the robot will be one-on-one.

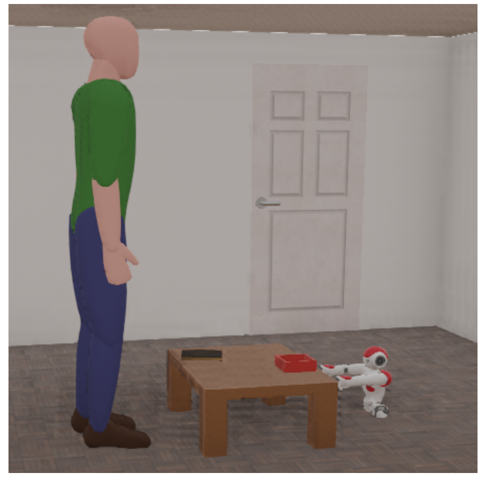

Fig. 3. A setup of a robot with mechanical facial appearance, small size, and non-legged configuration.

3) Artifacts: A custom base template for the humanoid robot will be designed. It will roughly be based on the Nao robot (Fig. 1), with arms, legs, a face, eyes, etc. For simplicity, a Wizard-of-Oz approach to interacting with the robots is used and they are controlled by researchers. The robots will each have the same prompts recorded in the same voice as an mp3 file; there is a procedural script to follow for the researchers. There will be no gestures as this is outside the scope of the experiment and we want to isolate any potential differences in responses to the static physical appearance only.

4) Procedures and Measures: In the experiment, the children are asked to interact with and learn a simple topic from the robot. In our experiment, we will try and teach kids a simplified version of fractals and the coastline paradox since it is easy enough to understand for a child but is also rarely taught in traditional schools. This will be taught by a pre-generated script played by the robot and there will be no additional help given outside that. The researchers only chose when to play/advance the script forward. After the interaction, a set of questions will be asked to help answer our research questions.

Firstly, to determine how palatable the robot's appearance was to the children, we ask them "How comfortable did you feel when you first saw the robot?" and then judge the responses on a 5-point semantic scale from very comfortable to not at all comfortable.

To answer the second research question, a series of follow-up questions to test the students' knowledge will be administered by the researchers. These will consist of a fact retrieval/summary question, i.e. What did you learn about the topic from the robot, and an analysis/insight question, e.g. Is x also an example of a fractal? What other examples can you think of? Thus we can determine to what extent the child understands the topic. They will be given a grade from 0-2 for each question, with 0 indicating failure to answer the question sufficiently, 1 being somewhat answered and was on the right track, and 2 successfully answering. The answers will be judged by the researchers and each participant will receive the same two questions.

B. Expected Results

The experiment has not been conducted, as this is merely a proposal for the experiment subject to change. We can, however, discuss the expected results based on our current understanding.

The literature has been fairly consistent in stating that children prefer smaller, more human robots. Thus for the first part of the experiment, the basic emotional responses, we can assume that the small size will achieve the highest score of comfort. For the level of facial anthropomorphization, it is unknown if the children will deem the doll face as in the uncanny valley in comparison to the more basic Nao-based face. Finally, there has also been little research done on the torso model of the social robot, but if we are to extrapolate the literature stating more human features are better, we can assume that the model with legs would perform better. Likewise, we must also consider the fact that legs, in conjunction with the size and facial anthropomorphization, could end up in the uncanny valley. Research has shown that a greater level of comfortability significantly predicted affective learning [15]. Consequently, we may assume that the more comfortable the student is, the better the learning outcomes.

As aforementioned, this is a 2x3x2 mixed factorial experiment, so we will have 12 distinct combinations of robots. This broad range is large enough to determine the effect each factor has on the learning outcomes, and also to see how these factors interact and influence each other, and to what extent.

V. Discussion

By determining which design combination of the robot has the highest comfort score, we can determine what children value in robots and how to design them to be more familiar and friendly. We can also distinctly see the effects each factor (size, facial anthropomorphization, and torso design) has on the perception of the robot by the children. Furthermore, by using the factorial design, we can analyze to what extent these factors influence each other, and the learning outcome. Finally, using much of the same analyses, we can determine how well the learning outcomes were achieved by examining the children's responses to the topic questions to investigate their level of understanding and how the robot's appearance affected it.

There are also a few limitations to the proposed study. For instance, while 60 is a fairly reasonable sample size for most HRI experiments since we have 12 combinations of robots, it only allows for 5 students for each combination. This small sample size may result in skewed results that are not generalizable. 60 was chosen as a larger number was thought to be difficult to obtain, but the sample size is a factor that must be considered. The age range may also be too large, as there may be significant differences between 6-13-year-olds. However, this rather large range was also chosen due to the need for a large sample size; it will be difficult to find 60 children of the same age, in the same school, willing to participate in a study. This may also affect the study's generalizability and accuracy. Finally, there is an individual bias that these children may have due to their upbringing, gender, or any personal experience that may affect the results; we have done our best to counter them by choosing children of a similar age and academic background, but this must be considered.

VI. Conclusions

As social robots have become increasingly popular in early childhood education due to their ease of accessibility and cost, children have consequently increasingly relied on them as an education tool. To ensure that these tools are effective in teaching and achieving learning outcomes, they must be physically designed in a way that maximizes these aforementioned duties. We have developed a method to experimentally determine and analyze the effects of 3 physical design choices, level of facial anthropomorphization, size, and torso design, to understand how to better design a social robot to achieve optimal learning outcomes for childhood education. These designs are evaluated by having children interact and learn from these robots in a predetermined script, and assessing their effectiveness in a classroom setting. The students are then asked questions and graded on their understanding.

Thus, we gain a deeper understanding of child psychology and how to achieve more optimal social robot design. Future researchers may use our robot template to investigate more physical design choices, such as colour, material, build, etc.

VII. Future Work

In the future, more design factors may be investigated, to gain a more comprehensive knowledge of social robot design. Furthermore, the participants may be altered to analyze the influence of physical design choices on other groups of children, such as children with learning disabilities and special needs.

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