CREATION AND TESTING OF A SOCIAL ROBOT GUIDELINE

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              Guideline

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ABSTRACT

Creation and Testing of a Social Robot Guideline

Sarika Singhal

For this thesis, I created a guideline for socially assistive robots (SARs), and used it to evaluate a reading comprehension based social robot.

To create the guideline I extracted relevant details from published standards about toy safety, radio equipment, electromagnetic compatibility, internet of things security, ethical considerations for human-computer interaction, and data privacy. I then sent a summarized version to experts in the field for feedback. I received seven responses, five of whom were from researchers in academia. The sample size was too small for statistical analysis. Survey responses identified additional areas, such as interactivity and aesthetics, for the guideline.

I evaluated a reading comprehension based social robot called HAPI the Librarian with my newly created guidelines. Using HAPI, I found that the guidelines worked, but needed improvement. Improvements suggested for the next iteration of the guideline are to provide better directives for intangible concepts such as ethics and data privacy. Additionally, the guidelines should help to identify characteristics that raise ethical or data privacy concerns.

Overall, these guidelines can be applied to socially assistive robots designed from scratch or purchased off-the-shelf.

ACKNOWLEDGMENTS

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Chapter 1

INTRODUCTION

Socially assistive robots (SAR) interact with people to help improve their quality of life [7]. Engineering standards are used across industries as a form of measuring adherence to a set of agreed upon and tested regulations [8]. However, a set of standards for SARs cannot be found in any of the leading international standards organizations.

1.1 Hypotheses and Research Questions

This thesis addresses two research questions and hypotheses:

1. Given the lack of standards for the development and evaluation of social robotic systems, can principles from existing standards in different domains be used to craft guidelines for socially assistive robots (SARs)?

2. To what extent can a novel SAR guideline be evaluated with a specific use case?

Hypothesis 1: By synthesizing selected standards from multiple domains (such as hardware, software, human-computer interaction, etc) as well as expert feedback, a guideline will be developed that can be applied for all social robots.

The guidelines will be used to assess the quality of a social robot in a variety of spheres. Previous robot testing procedures include software quality tests as well as test procedures for the safety of hardware components. Relevant details from existing standards for physical components, such as hardware, and intangible components,

such as ethics and data privacy, will be extracted for the guideline. Surveying experts in the social robotics field will provide feedback on how the SAR guidelines can be improved.

Hypothesis 2: The compiled guidelines will be applicable when used for reading based social robots.

In this thesis, the created social robot guidelines will be evaluated with a reading based social robot. A pass/fail approach would evaluate the guideline. Based on the evaluation we can determine if the social robot passes, as well as the strengths and limitations of the newly developed social robot guidelines.

1.2 Approach

To answer these hypotheses I first conducted research on existing quality engineering work done on SARs. Next I focused on the first hypothesis and research question. I extracted details relevant to SARs from existing standards to craft a SAR guideline. A summary and survey of this guideline was sent to experts in the field for feedback on how the guidelines could be improved. The second hypothesis and research question are dependent on the completion of the SAR guideline. The guidelines were created to be executed with a pass/fail approach. I applied my guidelines to a reading comprehension SAR called HAPI the Librarian.

This thesis creates a SAR guideline, assesses the contributions made by the surveyed experts, and evaluates the usefulness of the SAR guideline. In this thesis, the phrase "I" refers to work done by the researcher Sarika Singhal, and the phrase "we" refers to work done by the researcher Sarika Singhal and Committee Chair Dr. Espinoza Wade.

Chapter 2

BACKGROUND

Childhood literacy is instrumental in creating the building blocks of communication in humans. Learning how to read at a young age helps children develop reading, writing, and language skills. These skills include "oral language, phonological awareness, print awareness, and letter knowledge [9]." Studies show children with difficulties learning how to read are at risk of future academic failure and struggle with social and emotional issues [9].

According to the United State's National Assessment of Education Progress, NAEP, in 2019 66% of children age 9-10 scored at or above the NAEP's Basic Reading Assessment Level, a 1% decrease from 2017 [10]. The NAEP reported the following student groups have lower scores in 2019 than 2017: students attending public schools, students in the Northeastern, Midwestern, and Southern regions of the US, and students identified as having disabilities [10]. The World Health Organization's announcement that COVID-19 was a pandemic in March 2020 certainly didn't help matters [11]. The pandemic resulted in "1.5 billion students" around the world becoming no longer able to attend class in person [11]. A 2021 Stanford study found that due to COVID-19, the oral reading fluency of American children ages 7-9 is "about 30% behind what's ... expected in a typical year [12]." Given this significant delay in child literacy development, an entire generation is at risk of falling academically behind compared to previous generations. Serious work must be done to address this drastic fall in childhood literacy.

The pandemic caused most US schools to shift to online learning. The abrupt transition for both educators and students was a key factor to learning loss [12]. Fortunately, by Fall 2020, the quality of instruction improved, compared to Spring 2020, regardless of teaching format [12]. Across the country, various states have dedicated state funding or passed laws to improve literacy rates [13]. Eighteen states and Washington DC used COVID-19 funds to train educators on a new method to teach reading [13]. A Texas state law requires public schools to intervene and tutor students who fail state tests [13]. While well intentioned, these measures aren't enough to keep up with the high volume of children who need tutoring and extra help.

Socially assistive robots (SAR) are robots specifically designed to "interact and work with humans... [to] help them achieve their goals and improve the quality of their lives [7]." During a human-robot interaction (HRI), a social robot is treated as another being rather than an object (e.g., an aide, friend, or mentor). This is partially evoked by anthropomorphizing the robot's physical appearance [14]. As a result, SARs can be used in "education, health, entertainment, and communication [15]." In education, social robots have been used to help teach language, STEM classes, and handwritng [16, 17]. In the medical field, social robots are used with children or the elderly [18]. Advantages of SARs include the increased time a SAR can spend on a task and the implementation of SARs to complete receptive tasks.

As the use of social robots has risen, so has the number of social robots geared toward young children [19, 20, 21, 16] Children exposed to social robots at a young age have been found to treat social robots as a peer [19]. A 2007 study from UC San Diego found that over the course of 5 months, preschoolers began to view a social robot as their peer [19]. Behaviours included preschoolers touching the robot as they would their peers and placing a blanket over the "napping" robot. A 2018 study validated four assessments of social robot interactions with children. The four assessments are

inclusion of other in a self task, social relational interview, narrative description, and self-disclosure task [20].

Since prior research shows children are open to social robot interaction, social robots serve as a tool for adults to increase impact on a child. To encourage young children to read, engagement and interaction is necessary[9]. Engagement strategies include active discussions about the text, "drawing attention to the print", and creating a learning atmosphere with scheduled reading sessions [9]. These are tasks social robots may be able to conduct with young children in regard to education.[22].

Researchers and clinicians have designed social robots geared toward children's education [22, 23, 24]. Tega (Figure 2.1) is a social robot that is programmed with an Android phone to display information for children to interact with and practice reading [22].
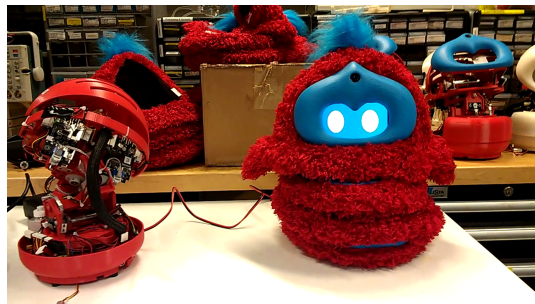
Figure 2.1: Tega Helps Children Practice Reading

Moxie (Figure 2.2) is a "play based" social robot designed to help children ages 5-10 develop their social and emotional skills [23]. A six-week study conducted with Moxie and children with autism spectrum disorder found improvement in the children's conversational skills, emotion regulation, and self esteem [23].

Not all social robots geared toward children are developed and tested by researchers. Luka (Figure 2.3) is a toy owl robot that connects to a cellphone app to read to kids

Figure 2.2: Moxie Interacts with Children Through Play

[24]. The robot's eyes are programmed to look down towards a book and read it out loud.

Figure 2.3: Luka Reads to Children

Reading robots are just one example of a social robot used to interact with people. Though the advantages and application domains of reading SARs are increasingly clear, there remains a lack of standardization for these systems, or all types of SAR more broadly. As introduction of social robots as helpful aides in daily life increases, quality engineering and quality assurance becomes valuable in assessing and improving social robot design. However, social robots lack across the board quality standards that address the robot itself as well as human-robot interaction. Quality standards and quality engineering analyze and aim to improve a product's design while also developing base line benchmarks that products must meet [25]. If these SARs are meant

to interact with young kids, passing quality standards would be an easy way to ensure these interactions are safe. The baseline also lets a potential consumer compare SARs and choose those which best match their needs. In the previously mentioned social robots, Tega and Moxie, social robot quality focused on HRI. Quality which is centered around these social robots' overall purpose asks the broad question: Do the interactions between the robot and child improve the child's literacy skills? Tega and Moxie lack testing on individual components or extreme use cases, quality testing measures that would belong in a standard.

Quality assessment of SARs for children remain limited to safety [26, 27]. A 2019 study examined the case study of a robot thrown at a person's head [26]. Researchers compared three materials, three thicknesses, and three impact velocities to find that objects covered with a thicker, softer material decrease impact . Another 2019 study used adults and children to program robots to recognize "aggressive" behavior [27]. Three robot toys of different sizes, shapes, and materials were subjected to five aggressive behaviors: drop, hit, pick up, shake, and throw. This research forms the groundwork towards incorporating responses to social robots experiencing aggressive behavior. Additional quality assessment domains include battery operation, sound production, and software quality. Similar products with published standards are robotic toys and the Amazon Echo Dot. Chapter 3 Guidelines Research investigates established standards that will be used to create a SAR guideline.

The COVID-19 Pandemic exacerbated already dwindling national reading literacy rates among young children. SARs are a potential method to help educators provide children with the time and resources they need to learn and improve their scores. However, SARs lack across the board design guidelines that standardize basic components such as safety or software quality.

Chapter 3

GUIDELINES RESEARCH

3.1 Introduction

Since the creation and evaluation of social robots is relatively new, there are no estab-
lished, across the board design guidelines. In industry, such guidelines are generally
specified using standards. Standards provide a universal set of guidelines for "quality,
efficiency, and compliance" that can apply to any organization or product [28]. The
consistency provided by standards allows individuals to design "compatible" products
or "compare competing products [8]." There are multiple standards setting bodies at
national and international levels.

Standards set by international standards organizations are applicable to multiple mar-
kets across the globe. Keeping that in mind, I opted to focus my guidelines research
on leading international organizations which set engineering standards. These include
the following: International Organization for Standardization (ISO), European Union
(EU), the American Society for Testing and Materials (ASTM), and the Institute of
Electrical and Electronics Engineers (IEEE) [29, 30, 31, 8].

The ISO comprises of 167 member countries that work together to develop and im-
plement standards [29]. The EU is a 27-member organization whose standards are
applied to any product entering or used within the EU [30]. ASTM and IEEE stan-
dards are developed by industry professionals [32, 8].

Unlike the EU, the United States does not have a single 'umbrella' set of US standards.
Instead, they are a member of the ISO, ASTM, and IEEE. As a member of these

international organizations, products sold in the United States conform to the above international organization's specifications.

Currently, none of the above international standards organizations have established standards for social robots. The goal of this chapter is to make use of principles of standard design to develop a guideline for a socially assistive robot (SAR).

3.2   Approach

As noted earlier, standards for social robots are not established. My goal in this study is to analyze existing standards in related domains and develop a proposed set of guidelines for SARs. To narrow down my search from the vast range of existing standards, I took two approaches – 1. analyzing conformance specifications for existing social robots, and 2. directly identifying and researching specific standards relevant to SAR as suggested by common sense.

3.2.1   Conformance Specifications for Existing Social Robots

First, I looked up manufacturing conformance specifications of products that fall under "social robots."

I used the search term "social robot toy" to find existing social robots on the market. I specifically included the term "toy" because it would be a social robot aimed towards children and would certainly require passing standards if sold to a young audience. After identifying a robot, I searched "[robot name] conformity" to find its publicly available declarations of conformance.

Anki's Cozmo (Figure 3.1) is a children's toy robot that has a digital screen for a face and can be programmed to move. These are also characteristics of a social robot [33].

Figure 3.1: Anki's Cozmo Robot

Its EU Declaration of Conformity document shows that it must pass the EU's toy safety, radio equipment, and RoHS directives [34]. Toy safety and radio equipment directive (RED) will be added to my SAR guideline's scope. Though important, the environmental Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive does not directly affect social robots. It can be assumed that off-the-shelf parts used to build social robots pass RoHS compliance standards. However, it is always recommended that designers should refer to the RoHS standards when designing a SAR. As a result, RoHS will be listed in Section 3.9, Additional Guidelines/Resources section of the Social Robot Guidelines.

As previously discussed (Chapter 2), social robots are often used around children. If a young child is expected to interact with the robot, they should not be at risk of injuring themselves or the robot. Toy safety standards were created with this goal in mind. For our purposes, these standards are most applicable to robot's hardware and its user applications.

Devices designed to interact and communicate with human users also have relevance to SAR systems. I investigated in-home assistive devices including the Amazon Echo Dot's Declaration of Conformity [35]. I chose the Echo Dot for its ability to conduct voice interactions between a user and robot. The two relevant directives were the EU's RED and electromagnetic compatibility (EMC). For ease of accessibility, I chose to use the EU's RED and EMC standards over the ISO. The ISO and EU standards have a significant overlap in rules and regulations. To avoid redundancy, I chose to refer to the EU standards as they are also available publicly without requiring purchase.

3.2.2   Selection of SAR-Related Standards: Forward Approach

After investigating standards with existing systems, I then took a forward approach by directly identifying and researching specific standards relevant to social robots from the perspectives of roboticists and consumers. This forward approach addresses relevant domains not necessarily covered in existing social robots on the market. The selected standards are relevant to software quality, Internet of Things security, ethical standards for human-computer interactions, and data privacy.

Software quality is important for SAR systems, because, in order to function properly, they require reliable, working software which is less vulnerable to hacking and software crashes. Software quality standards provide guidelines that address the aforementioned risks.

The Internet of Things (IoT) consists of a "system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human interaction (1)." In this case, the word "thing" refers to "any natural or man-

made object that can be assigned an Internet Protocol (IP) address and is able to transfer data over a network (1). These devices can include social robots, so it is vital that social robots are equipped with IoT security measures. Security measures for IoT and social robots focus on protecting data and preventing hacking (1).

Human computer interaction (HCI) is a "multidisciplinary field of study" that focuses on "the design of computer technology and the interaction between humans and computers [36]." HCI's computer technology covers "computer science, cognitive science, and human factors engineering [36]." Ethical concerns in the HCI domain include "ensuring public interest, protecting confidentiality and privacy, and ensuring self-determination in research participation [3]." These ethical concerns remain applicable to social robots, specifically in the context of child-computer interactions (CCI).

Finally, interactive SAR scenarios utilize personally identifying information (PII) and personal health information (PHI) to be shared and recorded. As a result, it is important that data privacy measures are put in place to prevent fraud and identity theft [37].

3.2.3 Standards Selection

In summary, the forward approach and existing conformance specifications suggest that the following standards may be used to create a social robot guideline:

1. Toy Safety

2. Radio Equipment

3. Electromagnetic Compatibility

4. Software Quality

5. IoT Security

6. Human-Computer Interaction Ethical Standards

7. Data Privacy

8. Additional Guidelines/Resources

3.3 Toy Safety Standards

The EU's toy safety standard, 2009/48/EC, is written as a set of rules that can be tested on a pass/fail basis [2]. Annex II Particular Safety Requirements contains safety standards in regard to physical and mechanical properties, flammability, chemical properties, electrical properties, and hygiene. All standards falling under physical and mechanical properties, electrical properties, and hygiene are applicable to social robots [2]. For flammability and chemical properties, Standards 1 and 3 are applicable.

The ASTM's Standard Consumer Safety Specification for Toy Safety, F963-17, is much more comprehensive than the EU's 2009/48/EC [1]. Section 4 of F963-17 details safety requirements and Section 8 of F963-17 provides test methods. Table 3.1 displays standards relevant to social robots.

Table 3.1: Relevant ASTM Safety Requirements

Section Name	Section Number
Flammability	4.2
Sound Producing Toys	4.5
Accessible Edges	4.7
Projections	4.8
Accessible Points	4.9.1
Wires and Rods	4.10
Nails and Fasteners	4.11
Folding Mechanisms and Hinges	4.13
Cords, Straps, and Elastics	4.14
Holes, Clearance, and Accessibility of Mechanisms	4.18
Battery Operated Toys	4.25
Certain Toys with Nearly Spherical Ends	4.32

Standard 4.2's Flammability ensures the toy is protected against fire hazards. The Sound Producing Toys standard is necessary for robots that produce sound while interacting with children. Standards 4.7 to 4.11 detail relevant hardware specifications. Standard 4.13 Folding Mechanisms and Hinges targets children's furniture. This standard can be used as a basis for preventing pinch hazards in small robots. Standard 4.14 Cords, Straps, and Elastics can be applied to plug-in cables of the robot. 4.18 Holes, Clearance, and Accessibility of Mechanism has guidelines that will need to be shrunk for robots. These standards can be used to form hardware and electrical guidelines.

Section 8 of F963-17 includes guidelines on how to test or evaluate the relevant feature. Table 3.2 displays relevant tests for social robots from Section 8.

Table 3.2: Relevant ASTM Safety Test Methods

Test Name	Section Number
Normal Use Testing	8.5
Abuse Testing	8.6
Impact Tests	8.7
Torque Test for Removal of Components	8.8
Tension Test for Removal of Components	8.9
Compression Test	8.10
Flexure Test	8.12
Stalled Motor Test for Battery Operated Toys	8.17
Test for Toys that Contain Secondary Cells or Batteries	8.19
Test for Toys that Produce Noise	8.20
Test Methods for Locking Mechanisms or Other Means	8.26

In Section 8.5, normal use testing examines normal use "to ensure that hazards aren't generated through normal wear and deterioration [1]." Section 8.6 Abuse Testing examines scenarios with "foreseeable abuse" such as dropping or throwing [1]. Standards 8.7 to 8.10 are designed for toys geared to children ages 0 to 8, but can still serve as a jumping off point for creating social robot test procedures [1]. Appendix .1 contains Table 5: Test Parameters for Use and Abuse Tests from Section 8. This table provides parameters for different user age groups for tests 8.5-8.10 and 8.12. Annex 5 contains a flammability test procedure for solids and soft toys and Annex 8 is a design guideline for Battery Operated toys. These two annexes are also relevant for social robots. Standards 8.17 to 8.20 are applicable to battery operated robots that may also produce sound.

3.4 Radio Equipment and Electromagnetic Compatibility

Both the European Union's Radio Equipment Directive (RED), 2014/53/EU, and the Electromagnetic Directive (EMC), 2014/30/EU prescribe standards for documenting technical specifications [38, 39]. Both directives cover radio and electromagnetic equipment used in or sold within the EU. The directives ask manufacturers to look up and adhere to current acceptable operation standards as well as participate in conformance testing procedures.

The RED Annexes describe conformity assessment modules of technical documentation requirements ranging from manufacturing to the CE marking [38]. The EMC Annexes provided declaration of conformity procedures and technical documentation specifications [39]. Overall, the RED and EMC directives can be used to create a pass/fail set of standards for social robots. If a social robot is built with off-the-shelf parts, then it would pass RED and EMC specifications because the parts would conform to these specifications.

3.5 Software Quality

The ISO's Software Standard, ISO 5055, assess the security, reliability, performance efficiency, and maintainability of a software product [40]. The standard is designed to "identify and eliminate structural weaknesses before they cause operational problems [40]." Chapters 6, 7, and 8 are particular to note in ISO 5055 [41]. Chapter 6 lists and describes common weaknesses for each of the four factors of software assessment. A weakness is a portion of code susceptible to hacking or used to cause "malicious actions [42]." Chapter 7 provides the reference, role, and detection pattern for software

weaknesses. Additionally, Chapter 8 provides code for weakness detection. These three chapters broadly describe coding quality standards that can be applied to social robots.

The Consortium for Information and Software Quality (CISQ) helped develop ISO 5055 [40]. As a result, CISQ created a Common Weakness Enumeration (CWE) that describes over "800 known software weaknesses in software architecture and source code [42]." This document is also referred to within ISO 5055 [41]. The document has four tables containing common weaknesses for each quality factor. For example, Table 3 (Figure 3.2) shows a small portion of CWEs that fall under the reliability measure.

CWE #	Descriptor	Weakness description
CWE-119	Improper Restriction of Operations within the Bounds of a Memory Buffer	The software performs operations on a memory buffer, but it can read from or write to a memory location that is outside of the intended boundary of the buffer.
CWE-120	Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')	The program copies an input buffer to an output buffer without verifying that the size of the input buffer is less than the size of the output buffer, leading to a buffer overflow.
CWE-123	Write-what-where condition	Any condition where the attacker has the ability to write an arbitrary value to be written to an arbitrary location, often as the result of a buffer overflow.
CWE-125	Out-of-bounds read	The software reads data past the end, or before the beginning, of the intended buffer.
CWE-130	Improper Handling of Length Parameter Inconsistency	The software parses a formatted message or structure, but it does not handle or incorrectly handles a length field that is inconsistent with the actual length of the associated data.

Figure 3.2: Quality Measure: Reliability

The tables are directly relevant to a social robot guideline. In scenarios where the CWEs provided do not alleviate the quality issue, the user may find further detail in the full ISO 5055 standard.

3.6   Internet of Things Security

An Internet of Things (IoT) ecosystem allows multiple "web enabled smart devices to collect, send, and act on data acquired" within their ecosystem [43]. However, this increases the potential for an IoT ecosystem to be hacked or to lose private data. As the number of devises connected to an IoT ecosystem increases, the potential for hacking increases as well [43]. In an IoT ecosystem, data is sent to the cloud. Because data can be analyzed or stored in the cloud, these devices and the cloud could be vulnerable to hackers "obtain[ing] and sell[ing] user's personal data [43]."

The IoT portion of the Guideline will address five common challenges as well as provide suggestions for IoT security measures. They are: [44]

1. Software and Firmware Vulnerabilities

2. Insecure Communications

3. Data Leaks from IoT Systems

4. Malware Risks

5. Cyber Attacks

Overall, IoT security aims to "preserve privacy [and] security" while "guaranteeing the availability of services offered by an IoT system, [45]." An encompassing survey of IoT reserach from 2016 to 2018 by Hassan et al. found that the five most common IoT security measures are: authentication, encryption, trust management, secure routing protocols, and use of new technologies [45].

The guideline will recommend these five security methods as well as suggest some additional standards for a further in-depth look at IoT security. The IEEE provides

two such standards. They are: 2410-2021: Biometric Privacy and 2413-2019: Architectural Framework for the Internet of Things.

Biometric privacy can be used for authentication and identification security measures [46]. The architectural framework standard was created with stakeholder concerns in mind and can be applied to multiple industries [47].

3.7 Human-Computer Interaction Ethical Standards

To develop ethical guidelines for Human-Computer Interaction, HCI, I utilized review papers focused on ethics with HCI and Child-Computer Interaction (CCI). Since social robots are also used with children, it is important to examine ethical concerns in child-computer interactions (CCI). In this thesis and attached guideline, the term child refers to anyone under 18 years old in the context of CCI. Importantly, these populations include those who are developing, vulnerable, underprivileged, and with special needs [4]. Therefore, the importance of incorporating ethical considerations is critical.

In Human-Computer Interaction (HCI), there are two main sources of ethical codes: computing institutes such as the IEEE and the Association for Computing Machinery (ACM) and psychological institutes such as the American Psychological Association (APA) [3]. Computing institutes prioritize "technology related principles," while psychological institutes prioritize "issues specific to psychological professions" [3]. However, both types of ethical concerns overlap with social robots given that social robots are specifically designed to interact with humans.

Table 3.3 displays a list of ethical concerns highlighted in 44 HCI papers between 2010 and 2015 [3].

Table 3.3: Ethical Concerns for Human-Computer Interaction

Number	Ethical Concern
1	Human and Robots
2	Autonomy and Self Determination
3	Welfare of Participants and Researchers
4	Privacy
5	Individual Differences
6	Children Participants

The ethical concern "Humans and Robots" centers on human-robot interaction (HRI) [3]. HRI ethical concerns include "robot replacement" of human professionals and "minimizing risks" during HRI [3]. Numbers 2, 3, and 4 focus on the rights and well-being of HCI participants and researchers [3]. Participants have the ability to take part in or withdraw from research studies. While conducting research, both parties should be "protected against any incidents that may impact either their mental or physical" health [3]. HCI privacy concerns cover information collected in-person and online. The following section, 3.8, expands on the data privacy portion of the guideline. Individual differences include "cultural differences, age groups, and disability [3]." For a socially assistive robot, researchers need to account for individual differences of their participants. Consent from the child's "guardians or gatekeepers is a must for any child participating in HCI/CCI research [3]."

A review of 18 years worth of research papers in the CCI ethics domain by Van Mechelen et al. found 157 research papers that can be sorted into multiple ethical categories [4]. Table 3.4 lists the types of ethics CCI and social robots should cover as found by Van Mechelen et al.

Table 3.4: **Ethics Concerns in Child-Computer Interactions**

Number	Type of Ethics
1	Situational Ethics
2	Participation Ethics
3	Design Ethics
4	Everyday Ethics
5	Teaching Design Ethics
6	Teaching Everyday Ethics

Situational ethics primarily applies to the "research and design process" and includes scenarios such as ensuring all child participants leave a study "feeling as if they succeeded [4]." Participation ethics asks researchers and, in the case of this thesis, roboticists, to be aware of "children's values" when designing SARs [4]. Design ethics examines "the actual or potential impact of technology" to an individual and society overall [4]. Conversely, everyday ethics examines "interactions between people without an explicit link to technology [4]." Teaching design ethics functions as a "learning goal" aimed to "raise awareness about the impact of technology on people's lives and society at large [4]." Lastly, teaching everyday ethics also functions as a "learning goal" to prepare children to "deal with ethical challenges in daily life [4]."

Additionally, Van Mechelen et al found that in CCI, there are six primary "actors" that should be considered for ethical guidelines [4]. They are researchers and designers, children, parents and primary caregivers, educators, and domain experts [4]. These six "actors" are the target audience for this chapter of the guideline.

3.8   Data Privacy

For social robots, relevant data privacy regulations are the EU's General Data Protection Regulation (GDPR), California Consumer Privacy Act (CCPA), the United

States' Children Online Privacy Protection Act (COPPA), and the Health Insurance Portability and Accountability Act (HIPPA). These regulations must be followed if operating in the EU, United States, and California respectively. These regulations also serve as overall data privacy suggestions for social robots.

The GDPR applies to companies operating in the EU or processing the personal data of EU citizens [5]. If the company has fewer than 250 employees but processes data often and includes sensitive personal data, if must comply with GDPR [5]. Table 3.5 shows data protected by the GDPR.

Table 3.5: General Data Protection Regulation Protected Data

Data Type
Basic Identifying Information including: Name, Address, ID Numbers, etc
Web Data including: Location, IP Address, Cookie Data, RFID tags
Health and Genetic Data
Biometric Data
Racial or Ethnic Data
Political Opinions
Sexual Orientation

Under the GDPR, third parties working with organizations that own the original data must also comply with GDPR [5]. All data breaches must be reported within 72 hours to prevent fines.

Social robots used in healthcare settings must be in accordance with HIPPA [48]. As an entity providing treatment, payment, and/or operations in healthcare, all personal health information must be secure [48].

Social robots used in settings with children in the United States must be aware of the Children's Online Privacy Protection Act. This law "protects the privacy and

personally identifying information of children under age 13 using online services [49]."
COPPA allows parents some oversight of the information their children share. Under
COPPA, personal information also includes user behavior [49].

In 2018, the California Consumer Privacy Act (CCPA) became California law and
allows Californians to see all data collected by a company and the the third party
organizations this data is shared with within the past 12 months [6]. This law applies
to all companies that have Californian consumers and one of the following: $25 million
in annual income, have the personal data of at least 50,000 people, or collect at least
"50% of revenue from the sale of personal data [6]." Table 3.6 shows that the CCPA
covers more data than the GDPR [5].

Table 3.6: California Consumer Privacy Act Protected Data [6]

Data Type
Basic Identifying Information: real name, alias, postal address, unique personal identifier, etc
Online Data: IP Address, email address, account name, etc
Identifying Numbers such as: Social Security, Driver's License, Passport, or other similar identifiers
Characteristics of protected classifications under CA or Federal Law
Commercial information: records of personal property, products, or services purchased, obtained, considered, or other purchasing or consuming histories and tendencies
Biometric information
Internet and other electronic network activity information including browsing and search history, and information regarding a consumer's interaction with a website, application, or advertisement
Geolocation Data
Sensory Data: Audio, Electronic, visual, thermal, olfactory, or similar information
Professional or employment related information
Non-publicly accessible education information
Inferences drawn on the above information to create a consumer profile

The CCPA requires companies to provide equal service to users who opt out of having their data shared. Both the GDPR and CCPA hold companies accountable for protecting personal data, but the CCPA gives consumers greater access to their records [5, 6].

3.9   Additional Guidelines/Resources

During our investigation, we found standards with some overlap or which were tangential to SAR. The majority of information in these standards is not directly relevant; however, the additional information may be relevant depending on the application (for instance, in applications where parts are being constructed from scratch, etc.). How-

ever, if the component is not off-the-shelf, the designer should refer to the following standards:

1. Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)

2. UL Standard for attachment plugs

3.10 Implications

The following eight topics and their relevant standards serve as a foundation for a social robot guideline: hardware safety, radio equipment, electromagnetic compatibility, software quality, internet of things security, human-computer interaction ethics, data privacy and additional guidelines. A practitioner should prioritize hardware, software quality, internet of things security, and data privacy before RED and EMC. These domains contain multiple subsections applicable to social robots regardless of if they are made with off-the-shelf components. If a practitioner plans to build a social robot with off-the-shelf parts, components would already pass RED and EMC standards. However, hardware and software would be up to the practitioner, making them responsible for envisioning their social robots are safe and user friendly. HCI, IOT, and data privacy are non-physical attributes that a practitioner must be aware of to protect themselves and users from harm. The guidelines complied in this chapter will be used to answer Hypothesis 1.

Chapter 4

METHOD FOR RESEARCH QUESTION 1

4.1 Introduction

This methodology chapter outlines the method used to investigate and answer the following research question: Given the lack of standards for the development and evaluation of social robotic systems, can principles from existing standards in different domains be used to craft guidelines for socially assistive robots (SARs)? This chapter will also discuss justifications for and limitations of our approach.

4.2 Methods

Before formulating my research questions and hypotheses, I used Google and Google Scholar to learn about social robots and how they are used in industry or laboratory settings. Due to my background in quality engineering, I decided to make this thesis quality focused.

To answer the first research question, I did a targeted search and read existing standards relevant to social robotic systems. These existing standards originated from the International Organization for Standardization (ISO), European Union (EU), the American Society for Testing and Materials (ASTM), and the Institute of Electrical and Electronics Engineers (IEEE) [29, 30, 31, 8]. I received help from Sarah Lester to access the ISO and ASTM standards I needed since they were behind a pay wall.

Through a forwards and backwards approach discussed in Chapter 3, I decided to ultimately research the following SAR relevant standards:

1. Toy Safety

2. Radio Equipment

3. Electromagnetic Compatibility

4. Software Quality

5. IoT Security

6. Human-Computer Interaction Ethical Standards

7. Data Privacy

8. Additional Guidelines/Resources

For toy safety, I sourced my guidelines from EU and ASTM standards [2, 1]. Radio equipment and electromagnetic standards came from the EU [38, 39]. Software pulls from ISO 5055 and the Consortium for Information and Software Quality's Common Weakness Enumeration [41, 42]. Internet of Things safety originates from suggested security measures [44, 45]. The ethical guidelines cover both human-computer interaction and child-computer interaction. Sources originated from the IEEE and APA [4, 3]. Finally, data privacy guidelines are influenced by the EU's General Data Protection Regulation, California's Consumer Privacy Act, and the United State's Children Online Privacy Protection Act and Health Insurance Portability and Accountability Act [5, 6, 49, 48]. From all of these existing, relevant standards, I extracted tables and rules applicable to SARs.

In the guidelines, the original standard text is used as a source to write a shorter, less specific guideline. Any guideline section that uses off the shelf parts were given

guideline exemptions. These exemptions state that if the component was purchased commercially, it can be assumed it already passed its established standards. This exemption includes radio equipment and electromagnetic compatibility.

While these standards cover most aspects of social robots, they do not cover everything (for instance RoHS). As a result, the last section of the guideline lists other relevant standards as a resource to social robotists. Standards listed in this section include Restriction of Hazardous Substances (RoHS) and outlet plugs.

With the completion of the guideline, we were interested in obtaining feedback from experts on its utility. We created and conducted a survey to gather qualitative feedback from SAR experts. After receiving approval from the Cal Poly's Institutional Review Board (IRB), we compiled a list of 270 SAR experts to survey. They each received an explanation of the research, found in Appendix .3. They also received a link to a Google Forms Survey found in Appendix .4. In the survey, the IRB approved demographic categories were selected based on prior evidence suggesting differences in response to technology based on age/gender. Profession was selected to contextualize resulting statements regarding expertise with SAR systems. These experts were emailed on October 10th, 2022 and given until October 24th, 2022 to complete the survey. We determined an adequate feedback pool would be twenty responses.

Chapter 5

METHOD FOR RESEARCH QUESTION 2

5.1 Introduction

This methodology chapter covers outlines the method used to answer the following research question: To what extent can a novel SAR guideline be evaluated using a specific use case? The purpose of this research question is to test the guidelines created from research question one.

5.2 Methods

I chose a reading robot called HAPI (Hand Articulating Phone Interface) the Librarian as my specific use case for testing the SAR guidelines. HAPI was created by a Cal Poly Senior Project team in 2020 [50]. HAPI mimics a librarian by holding a phone in front of a participant shown by Figure 5.1. HAPI was designed to be used by teachers for students to improve their reading comprehension skills without a teacher or teaching assistant present. This robot was chosen because it is a SAR and readily available.

HAPI the Librarian was created by an interdisciplinary engineering senior project team at Cal Poly during the 2019-2020 school year. The team was asked to create an interactive socially assistive robot that can function as an aide in speech therapy for young children [50]. Interactions include "recognizing voice input and providing audio and visual instruction and feedback [50]."
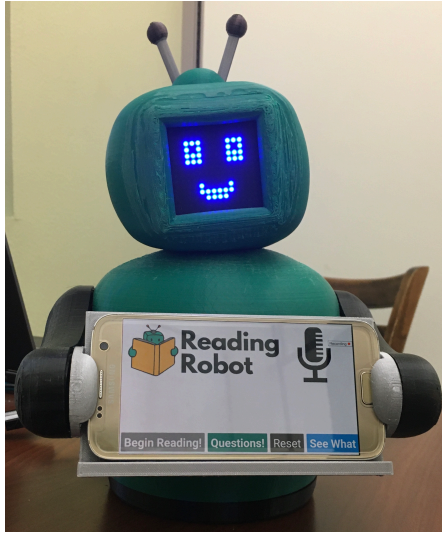
Figure 5.1: HAPI the Librarian

HAPI's shape was influenced by children's animated films and does not exceed a size
of H250mm x W200mm x D155mm (+/- 20mm) or a weight of 1.5kg (+/- 0.5 kg) [50].
The whole robot sits stationary but movement occurs in a phone tilting mechanism
and wiggling antennae as shown in Figure 5.2. HAPI also has a LED face allowing it
to show different expressions.

Figure 5.2: HAPI's Moving Features

To test the guidelines, I evaluated each item of the SAR guideline against the system using a pass/fail approach for each item. The hardware chapters of the guideline have two parts: hardware safety and hardware testing. Due to timing constraints and the existence of only one HAPI, guidelines that require hardware testing were skipped. However, the senior project report contains some testing documentation that can be referenced where applicable to cover a mechanical evaluation.

I documented why HAPI passed or failed for every item. The documented reasons will be used in the results to show how HAPI fares against the guidelines and logic used.

Chapter 6

RESULTS FOR HYPOTHESIS 1

6.1 Introduction

This chapter will describe the results of Hypothesis One: By synthesizing selected standards from multiple domains (such as hardware, software, human-computer interaction, etc.) as well as expert feedback, a guideline will be developed that can be applied for all social robots. This chapter, explains what the guideline covers and will provide the survey responses from SAR experts.

6.2 Creation of SAR Guideline

Appendix .2 contains the social robot guideline created by extracting relevant principles from existing standards. The guideline's chapters are organized by category. These categories include physical components, power and safety considerations, software quality, and privacy and security concerns. As a result, the guideline's chapters and subsections are as follows:

1. Hardware Safety

    (a) Physical and Mechanical Properties

2. Hardware Testing

    (a) Hazardous Content

    (b) Use and Abuse Testing

    (c) Stalled Motor Test for Battery Operated Robot

    (d) Tests for Robots Containing Secondary Cells or Batteries

    (e) Tests for Robots that Produce Noise

    (f) Tests for Locking Mechanisms or Other Means

3. Battery Operated Robots

4. Flammability

5. Chemical Properties

6. Hygiene

7. Sound Producing Social Robots

8. Electrical Properties

9. Radio Equipment

    (a) Off the Shelf Parts

    (b) Original Parts

10. Electromagnetic Compatibility

    (a) Off the Shelf Parts

    (b) Original Parts

11. Software Quality

    (a) Maintainability

    (b) Efficiency

    (c) Reliability

    (d) Security

12. Internet of Things Security

    (a) Common Challenges

    (b) Suggested Security Measures

    (c) Relevant IEEE Standards

13. Ethics and Human-Computer Interaction

    (a) Concerns of Human-Robot Interactions

    (b) Ethical Spheres of Child-Computer Interactions

14. Data Privacy

    (a) Region Specific Data Privacy Established Standards

    (b) Basic Data to be Kept Private

15. Additional Guidelines/Resources

This guideline will function as a pass/fail checklist with references to relevant testing standards that will be amended as needed to execute a SAR test. A pass/fail approach is the easiest way to apply the guideline. For example, under hardware safety, either the SAR has accessible sharp edges, in which case it fails, or the SAR does not, in which case it passes. Refer to Chapter 7: Results for Hypothesis 2 for results on using the pass/fail checklist approach on a SAR. Refer to Chapter 8.3: Discussion for Hypothesis 2 for a discussion on said results.

6.3 SAR Guideline Survey Feedback

Seven responses to the survey listed in Appendix .4 were received. All survey results can be found in Appendix .5. The survey was split into two subsections: Demographics and SAR Design Guideline.

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6.3.1 Demographics

The demographics of the survey participants are as follows in Tables 6.1 and 6.2.

Table 6.1: Participant Age

Age	Number of Participants
25-34	5
35-44	1
Prefer Not to Respond	1

Table 6.2: Participant Gender

Gender	Number of Participants
Gender: Female	3
Gender: Male	3
Gender: Prefer Not to Respond	1

Their experience with SAR systems are listed in Table 6.3 below.

Table 6.3: Participant Experience with SAR Systems

PID	Profession	Yrs. in Field	Area of Expertise	Target Population	SAR Used
1	Independent Scholar	6 - 10	Human-robot interaction, child-robot interaction, education, language learning	Children (neurotypical)	Designed
2	Researcher (Academia)	16 - 20	Socially aware AI	Adults (neurotypical)	Purchased Commercially
3	Researcher (Academia)	11 - 15	Human-robot interaction	Children (neurotypical and impaired) Adults (neurotypical and impaired)	Designed
4	Researcher (Academia)	6 - 10	Design, human-robot interaction, minimal robots, speech interaction	Adults (neurotypical)	Designed
5	Researcher (Government)	< 5	Human Factors Psychology	Adults (neurotypical)	Designed
6	Researcher (Academia)	6 - 10	Social psychology	Adults (neurotypical)	Purchased Commercially
7	Reseacher (Academia)	< 5	Machine learning, robotics, autonomous driving, opinion evolution dynamics	Adults (neurotypical and impaired)	Purchased Commercially

Based on Table 6.3, most participants have 6-10 years of experience and focus on human-robot interaction. Five participants are researchers in academia. Only two of the participants have neurotypical children as their target population or use social robots/agents that are commercially purchased.

When asked about primary considerations for designing social robots/agents, participants were allowed to check as many boxes they felt answered the question. Table 6.4 shows the results ranked from most to least.

Table 6.4: Primary Considerations For Designing Social Robots

Primary Condition	Number of Participants
Functionality	7
Interactivity	6
Safety	4
Aesthetics	2
None of the Above	0

Table 6.5 shows each participant's response when asked how they assess suitability of their SAR system prior to deploying with humans.

Table 6.5: Assessing SAR Suitability

PID	Response
1	Feedback and testing with all stakeholders - e.g. children, parents, educators, researchers
2	Use students before using people [sic]
3	Look over and test capabilities
4	Wizard-of-oz testing
5	I'm not really sure what you mean by "suitability" here. From a safety standpoint, in our embodied robot studies, we do not allow human participants to be in close proximity to the robots, reducing the likelihood of potential injury.
6	Since we usually buy available robots we heavily rely on previous experiences of colleagues.
7	This is a good question. I think one way to assess suitability is doing pilot/full experimental studies with participants (in line with the intended end user). Measure different responses both quantitative (like Heart rate, galvanic skin response, EEG (maybe)) and qualitative (like NASA TLX form, likert scale questionnaire (tailored for the study)). Then compare with a baseline and prove that the SAR is helpful to improve some performance measure. If we are concerned about the safety, then it has to come at the design phase and also pre-pilot/experiment stage where we as researchers test out the safety in both usual scenarios and also in edge case (very important to test for safety in the edge cases).

6.3.2 SAR Design Guideline

Next, participants were given Table 6.3.2 outlining the design considerations and their characteristics I used in the guideline. All responses are given in reference to this table.

Table 6.6: Social Robot Design Guidelines

Consideration	Characteristics
Hardware Safety	Physical / mechanical properties
Hardware Testing	Hazardous content, Use/abuse testing, Motor testing (battery operated), Noise testing, Locking mechanisms
Battery Operated	Flammability, Chemical properties, Electrical properties, Hygiene, Sound producing systems
Software Quality	Maintainability, Efficiency, Reliability, Security
Electromagnetic Compatibility	Off the shelf components, Original components
Radio equipment	Off the shelf components, Original components
IoT Security	Common challenges, Security measures, Relevant IEEE standards
Ethics	HRI concerns, ACM/CCI ethics

When asked if any design considerations were missing, participant responses are as follows in Table 6.7.

Table 6.7: Missing Considerations For Designing Social Robots

PID	Missing Considerations
1	Software - Privacy, Usability; Overall System: Interactivity, Usability, Fluidity
2	N/A
3	Expressiveness, Sensing, Degrees of Freedom
4	Interactivity, Data Requirements
5	N/A
6	N/A
7	Edge case testing. Maybe aesthetic because a SA robot has to be accepted/trustable by the intended end user.

Further discussion of the missing considerations appears in Discussion Chapter 8.2.2. When asked if any design considerations were unimportant, participant responses are as follows in Table 6.8. Refer to Chapter 8.2.2 for a discussion of the missing considerations listed by the two participants.

Table 6.8: Unimportant Considerations For Designing Social Robots

Participant Number	Unimportant Considerations
1	N/A
2	Hardware Safety
3	Radio, Electromagnetic, IoT Security
4	N/A
5	N/A
6	N/A
7	N/A

The last three questions in the survey used a Likert scale. Table 6.9 shows responses to the first question: If you design SAR systems, how likely are you to use this guideline? Table 6.10 shows responses by participant's professions. Table 6.11 shows responses by participant's use of designed versus commercially purchased SARs.

Table 6.9: Likeliness to use SAR Guideline for Design

Table 6.10: Likeliness to use SAR Guideline for Design - by Profession

Profession	Likert Scale Response
Independent Scholar	1
Researcher in Academia	1, 1, 3, 4, 7
Researcher in Government	6

Table 6.11: Likeliness to use SAR Guideline for Design - by SAR Type used

SAR Type	Likert Scale Response
Designed	1, 1, 3, 6
Purchased Commercially	1, 4, 7

Four of the seven participants were unlikely to use the SAR Guideline for design of SARs, while one was neutral and two were likely. The independent scholar and four researchers in academia reported that they were less likely to use the SAR Guideline, compared to one researcher in academia and the researcher in government. Both designed, and commercially purchased, SARs received high scores of 6 and 7 respectively.

Table 6.12 shows responses to the second question: If you purchase SAR systems, how likely are you to consider this guideline in selecting a new system? Table 6.13 shows responses by participant's professions. Table 6.14 shows responses by participant's use of designed versus commercially purchased SARs.

Table 6.12: Likeliness to Consider SAR Guideline for a New System
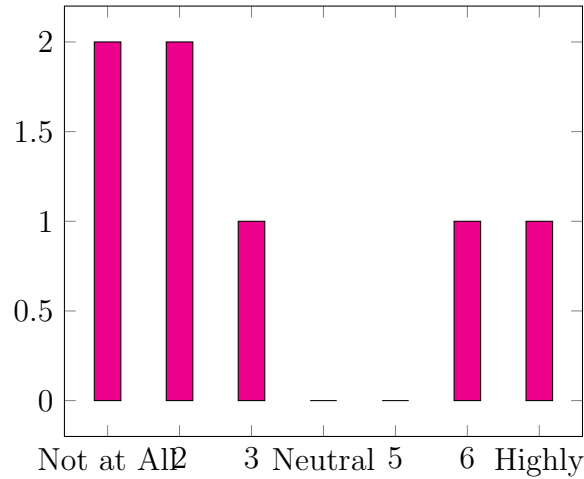
Table 6.13: Likeliness to Consider SAR Guideline for a New System - by Profession

Profession	Likert Scale Response
Independent Scholar	1
Researcher in Academia	1, 2, 3, 6, 7
Researcher in Government	2

Table 6.14: Likeliness to Consider SAR Guideline for a New System - by SAR Type used

SAR Type	Likert Scale Response
Designed	1, 1, 2, 3
Purchased Commercially	2, 6, 7

Five of the seven participants shared they would likely not consider the SAR Guideline when selecting a new system. Two participants who are researchers in academia and use commercially designed SARs, reported a high chance of considering the SAR guideline when selecting a new system.

Table 6.15 shows responses to the final question: If you teach SAR systems, how likely are you to use this guideline in instruction? Table 6.16 shows responses by

participant's professions. Table 6.17 shows responses by participant's use of designed versus commercially purchased SARs.
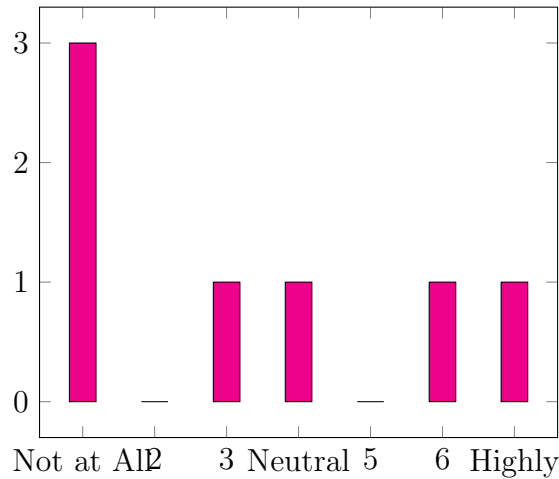
Table 6.15: Likeliness to Teach SAR Guideline
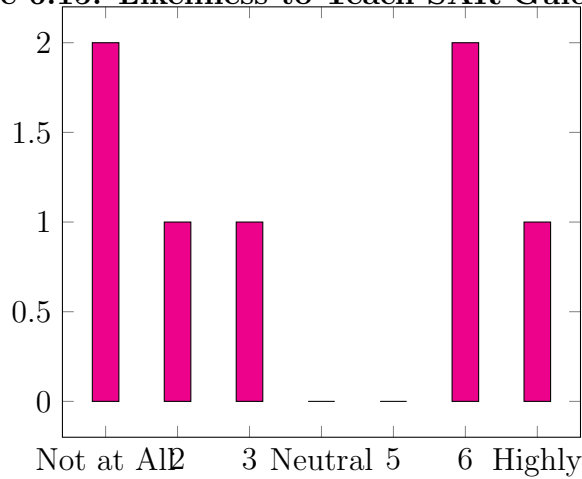
Table 6.16: Likeliness to Teach SAR Guideline - by Profession

Profession	Likert Scale Response
Independent Scholar	1
Researcher in Academia	1, 2, 3, 6, 7
Researcher in Government	6

Table 6.17: Likeliness to Teach SAR Guideline - by SAR Type used

SAR Type	Likert Scale Response
Designed	1, 1, 3, 6
Purchased Commercially	2, 6, 7

Four of seven participants shared they were unlikely to teach the SAR Guideline. Three of the five researchers in academia were unlikely to use the guideline in instruction regardless of SAR type.

Chapter 7

RESULTS FOR HYPOTHESIS 2

7.1   Introduction

This chapter will walk through the results of Hypothesis Two: The compiled guideline can be applicable when used with a SAR. I will state how HAPI passed or failed each item in the guideline.

7.2   Application of SAR Guideline

Prior to going through the guidelines, I first observed a demonstration of HAPI. Due to some mechanical wear on the robot, the antennae mechanism was temporarily removed to prevent it from hitting wires in the neck region. HAPI has two cables that plug into a Raspberry Pi and power source. A Raspberry Pi is a small, handheld single-board computer that anybody can program [51]. All recordings are stored on the cellphone attached to HAPI and do not go to the cloud. Figure 7.1 shows HAPI when the phone is recording.
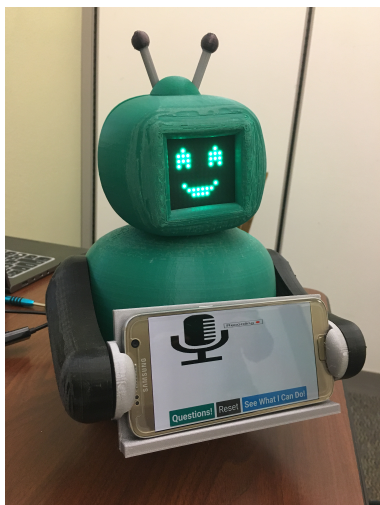
Figure 7.1: HAPI Recording

7.2.1   Chapter .2.1 Hardware Safety

1. No "accessible, potentially hazardous sharp edges" or points

   This measure passes, however there were two possible areas of concern. The first potential concern are the sharp corners of the phone holder as shown in Figure 7.2.
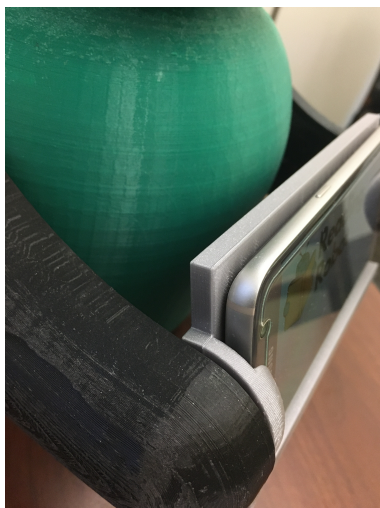
Figure 7.2: HAPI Sharp Phone Corner

The second item of concern was the potential of a sharp inside edge in HAPI's arms as shown in Figure 7.3.

Figure 7.3: HAPI Sharp Arm Edge

2. Folding mechanisms and hinges do not contain a "possible crushing, laceration, or pinching hazard."

   This measure passes. The phone holder has a maximum rotation of 20 degrees and is angled such that it would not pinch fingers. The antenna are designed to move up an down without any risk.

3. Robot and it's components (including cords, straps, and elastics) do not present a risk of "potential entanglement" or choking hazards [2].

   This measure passes, all components are contained inside the robot.

4. When subjected to force, the SAR does not break or "distort at the risk of causing physical injury"

   This measure could not be tested during the evaluation. However, the original documentation shows HAPI passed drop test guidelines developed during the senior project [50].

5. Robot surfaces must ensure that at "maximum and and minimum temperature, any accessible surfaces does not cause injury when touched"

   This measure could not be tested during the evaluation. However, the origi-

nal documentation shows HAPI passed temperature test guidelines developed during the senior project [50]. The cellphone is assumed to pass since it is a commercially available cellphone.

7.2.2 Chapter .2.2 Hardware Testing

1. Hazardous Content

   This measure passed on the evidence provided by the senior project documentation that all components were built by commercially available products [50].

2. Use and Abuse Testing

   This measure could not be tested during the evaluation. Original documentation shows HAPI passed drop test guidelines developed during the senior project [50].

3. Stalled Motor Test for Battery Operated Robot

   This measure does not apply since HAPI is not battery operated.

4. Tests for Robots Containing Secondary Cells or Batteries

   This measure does not apply since HAPI is not battery operated.

5. Tests for Robots that Produce Sound

   All sound from HAPI originates from the cellphone. The cellphone has an adjustable volume is is assumed to have passed relevant, established standards.

6. Tests for Locking Mechanisms or Other Means

   This measure passed.

7.2.3 Chapter .2.3 Battery Operated Robots

This chapter does not apply since HAPI is not battery operated.

7.2.4 Chapter .2.4 Flammability

This chapter passes since components used such as PLA are commercially available. The cellphone is assumed to have passed all relevant, established standards.

7.2.5 Chapter .2.5 Chemical Properties

This chapter passes since all components are commercially available and no product recalls of this nature have been made.

7.2.6 Chapter .2.6 Hygiene

This chapter passes.

7.2.7 Chapter .2.7 Sound Producing Robots

This chapter does not apply since all sound is produced from a cellphone.

7.2.8 Chapter .2.8 Electrical Properties

1. If in contact with children, a social robot that operates "from nominal 120V branch circuits" shall conform to 16 CFR 1505 (Requirements for Electrically Operated Toys or Other Electrically Operated Articles Intended for Use by Children)[2].
   This measure passes. Per HAPI's documentation, the voltage does not exceed 24V [50].

2. Where applicable, the robot provides protection against electric shock or other electrical hazards.

This measure passes. All wires are insulated. Per Figure 7.4 the bottom two sockets only allow their respective power or Raspberry Pi plugs. The hole above the power socket is used to determine if the light for the Raspberry Pi is on, indicating the Raspberry Pi is working. While all wires inside the robot are properly insulated, it is worth noting the potential risk of fingers stuck in the hole and tangling with the wires.

Figure 7.4: HAPI Electrical Hazard Protection

3. The robot must be designed and manufactured in such a way that [1]:

   (a) Any and all radiation generated is "limited to the extent necessary for the operation of the [robot], and must operate at a safe level in compliance." This measure passes as there is little to no radiation produced.

   (b) the [robot] "operates safely even when the electronic system starts malfunctioning or fails due to failure of the system itself or an outside factor." This measure passes as a failure of the system equates to HAPI not moving.

7.2.9 Chapter .2.9 Radio Equipment

This measure passes as all related components are purchased off the shelf.

7.2.10 Chapter .2.10 Electromagnetic Compatibility

This measure passes as all related components are purchased off the shelf.

7.2.11 Chapter .2.11 Software Quality

This measure conditionally passes. While it is proven HAPI's software works functionality wise, the documentation is lacking. Additionally, I lack the software background required to properly test this chapter. It should be noted at all coding for the app used with HAPI is created on Kodular [50].

7.2.12 Chapter .2.12 Internet of Things Security

This chapter does not apply since the Raspberry Pi does not need to connect to wifi for HAPI to work. Since all recording are saved to the cellphone, no information leaves the device.

7.2.13 Chapter .2.13 Ethics and Human-Computer Interaction

This chapter lacks measures that can be assessed on a pass/fail basis. The following observations were made that fall under the realm of this chapter. HAPI relies on Google's voice recognition software to "hear" the participant's response [50]. HAPI's LED face has four settings shown in the below images.
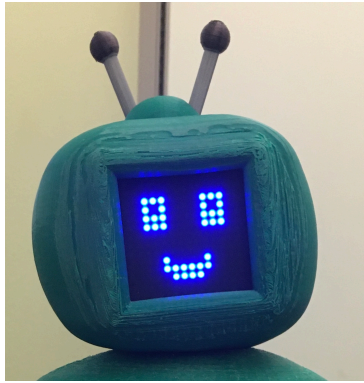
Figure 7.5: HAPI Resting Face
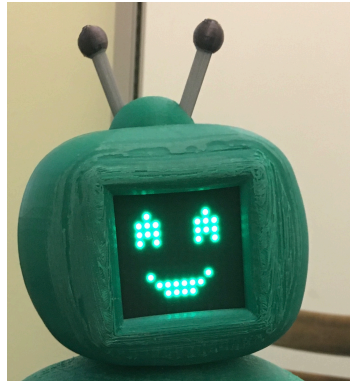
Figure 7.6: HAPI Correct Answer Face
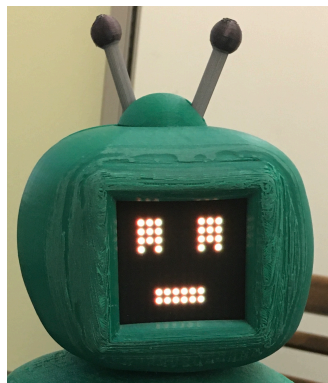
Figure 7.7: HAPI Incorrect Answer Face
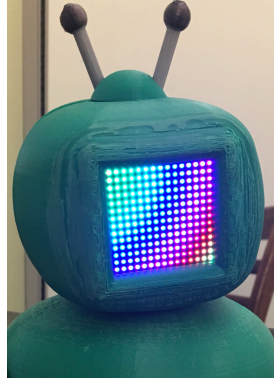
Figure 7.8: HAPI Completed Questions Face

Additionally, aside from the programmed questions, HAPI has been coded to speak phrases for correct and incorrect answers. For incorrect answers, HAPI's responses are:

- "Almost! Let's try again."

- "Let's listen to that question again."

- "Good try! Let's listen again."

- "You are so close. I'll say that question again."

- "Not quite. You're on the right track."

For correct answers, HAPI's responses are:

- "Great job! Let's move on!"

- "That's correct! Let's keep going!"

- "Perfect. You are doing a great job!"

- "Awesome! Great work."

- "Hmmmmm I think you're right. Well done."

7.2.14 Chapter .2.14 Data Privacy

This chapter provides established standards and a summarized list of basic data to keep private. The following observations were made that fall under this chapter. HAPI was created using MIT App Inventor. The app relies on Google's text-to-speech function. The Raspberry Pi does not use wifi and all data is saved to the attached phone. It is expected that Google's text-to-speech function passes Data Privacy standards. Hence, this measure passes.

Chapter 8

DISCUSSION

8.1 Introduction

This chapter contains two discussion sections. The first section discusses the results of Hypothesis 1. The second section discusses the results of Hypothesis 2.

8.2 Discussion for Hypothesis 1

This section will discuss creating the social robot guideline and survey responses.

8.2.1 Creation of SAR Guideline

Due to the nature of Hypothesis One, the work done in Chapters 3 and 6 shows it is possible to create a SAR guideline (found in Appendix .2). I was able to send a summarized version of the guideline with a survey to experts in the field and receive feedback.

Given the timeline of this thesis and the academic year (began in January 2022 and defended in December 2022), the list of potential guidelines and relevant standards is limited to what could have been researched, implemented, tested, and analyzed within the nine month time frame.

For a second iteration of the design guidelines, work should be done in two areas. First, the new version of the guidelines should implement feedback provided by the

survey responses. For further details on their feedback, refer to Chapter 8.2.2. Second, more research should be done to expand the scope of social robots to develop the guidelines. In this thesis, the initial starting point was social robots aimed at improving childhood literacy. As a result, the guidelines are skewed towards SARs for children more so than SARs geared toward adults or users of all ages. Additionally, the extended research would provide more general guidelines, such as how to design a SAR without an uncanny valley appearance.

For a further discussion on SAR guidelines, more specifically it's ability to be applied, refer to Section 8.3.

8.2.1.1 Summary

The list of potential guidelines and standards to adapt for SAR was constrained by the nine month time frame for this work. In order to maximize effectiveness of the allocated time, I prioritized researching the existence of a SAR guideline and relevant standards. A guideline was developed by synthesizing standards from different domains. After creating the guideline, they were subject to expert feedback and used to assess a SAR.

8.2.2 SAR Guideline Survey Feedback

Per Tables 6.1, 6.2, and 6.3, most participants were young (between 25 to 35 years old) and researchers in academia. Since most of the participants are young, it makes sense that their experience in the SAR field was primarily 6 to 10 years. From Appendix .5, one participant stated they are between the age of 25-34 and have 11-15 years of experience in SAR. Their years of experience indicates that they must be older and might have selected the wrong age range box.

Participant 1's response to assessing SAR suitability in Table 6.5 is similar to most reported SAR field testing in which all stakeholders are involved. Participant 2's background as a researcher in academia explains their access to students as test participants. Participants 3 and 4 have a similar response to Participant 1 and use designed SARs. Due to the format of the survey, I was unable to clear up Participant 5's confusion. Their follow up response regarding safety makes sense since they use a designed SAR. Since Participant 6 uses commercially purchased robots, relying on their colleague's previous experience helps them expand their knowledge base and make informed decisions. The provided suggestions by Participant 7 makes their use of commercially purchased SARs irrelevant.

Table 6.7 listed missing considerations for designing social robots. While keeping in mind the small pool of participants, I will asses how well the missing considerations would fit either within the existing guidelines or where they would be in a following iteration of the guidelines.

Participant 1 suggested software privacy and usability as well as interactivity, usability, and fluidity within the overall SAR system. Since software privacy overlaps with data privacy, it would not be included in the next guideline iteration. Software usability evaluates a user's experience with a social robot's software [52]. In the next iteration of the guideline, software usability can be incorporated as a test in the software chapter.

Two participants (1 and 4) suggested interactivity as missing considerations. Interactivity is a key component to testing a social robot's function and would assess human-robot interaction [7]. Interactivity would be added as its own chapter in the guideline that would outline HRI expectations and refer to the ethics chapter since the robot's interactivity should be cognizant of individual differences.

A social robot's usability can be assessed via a numbered scale or through interviews [53]. In the next iteration of the guideline, usability would be a subsection of the interactivity chapter. It would also be split into two parts. The first part would have universal usability guidelines for social robots regardless of the user. The second part would provide testing procedures with room for amendments to better fit the specific social robot.

Finally, Participant 1 suggested fluidity. Fluidity assesses how smoothly a robot moves [54]. In the next iteration, fluidity would be part of a chapter dedicated to assessing robot movement a subsection of which would be fluidity.

Participant 3 suggested expressiveness. This includes anthropomorphizing a SAR and avoiding the uncanny valley effect [14]. A subsection of the Interactivity chapter would suffice to ensure the robot's visual interaction is user friendly. Similarly, Participant 7 suggested aesthetic so a SAR is "accepted/trusted" by the end user. Along with anthropomorphizing a SAR, this could include the SAR's shape and artistic choices to convey the robot's visual expressions [55].

Participant 3 also suggested sensing. For social robots, this mean's the robot's ability to sense and react to physical touch [56]. This feature could either be a subsection of the Interactivity chapter or the Robot Movement chapter as both actions and feedback are dependent on how well the robot's sensors work. Finally, they suggested degrees of freedom. Degrees of freedom examines robotic movement and would be a subsection of the movement chapter.

Along with interactivity, Participant 4 suggested implementing data requirements. Data requirements approach identifies the relevant data requirements prior to collecting and analyzing the data [57]. For social robots, this would mean work must be done on the initial software to implement data requirements.

In addition to aesthetics, Participant 7 suggested edge case testing. This is already incorporated into the guideline as Abuse Testing in Section .2.2 Hardware Testing. The next guideline iteration can add edge case testing to the Battery Operated Robots, Sound Producing Robots, and Software Quality chapters.

In the next iteration of the guidelines, chapters need to be added that provide guidance on user experience with the robot and robot function.

Table 6.8 listed suggested unimportant considerations for designing social robots. Participant 2 suggested hardware safety. The hardware safety guideline was written with child users in mind and it is necessary that designers are aware of established safety measures for products geared towards children. Participant 3 listed radio equipment, electromagnetic compatibility, and IoT Security. Although the radio equipment and electromagnetic compatibility chapters heavily rely on their corresponding EU standards, it is necessary to acknowledge the role they play in robots. Internet of things security has some overlap with data privacy. As mentioned previously, software privacy was a suggested consideration, highlighting the importance of privacy and security of the robot's code and collected data.

Table 6.9 is the first of three Likert scale response questions from the survey and asks participants how likely they are to use the guideline. Overall, the response was negative. The government researcher and one researcher in academia reported the only two positive responses. The "6" given by the researcher in government could have been due to the fact that internal government standards and regulations are typically held at a higher level than academic or commercial regulations (for example a comparison of military standards to commercial standards). Since no SAR guideline exists, but SARs often interact with people of all ages and handle sensitive data, the SAR guideline this thesis creates is a good first step. By referencing the results in Appendix .5, the "7" given by the researcher in academia could have been

due to their expertise in robotics and autonomous driving. Not only would SAR guidelines advance the field of robots, they lay some initial groundwork for guidelines and eventual standards for autonomous driving.

Table 6.12 is a Likert scale response to using the guideline when selecting a new SAR system. The responses were negative except for one "6" and one "7" by two researchers in academia. Table 6.14 shows both researchers in academia who gave these scores have a background in using commercially purchased SARs. I found this surprising since I would have expected that a SAR commercially purchased would have been more likely to undergo some form of guideline assessment compared to a designed SAR.

The final Likert scale in Table 6.15 asks how likely is it that the guideline would be used in instruction. It tracks that the independent scholar has no plans to teach the guideline. Two of the five researchers in academia stated they were likely to teach the guidelines. As for the three negative responses, it would be worth considering what classes those researchers teach and how the guideline would fit with the curriculum. It was unexpected to see the government researcher also state they are likely to teach the guideline. Since this individual is not an educator, it is possible they gave a "6" for its perceived utility as an educational component.

If I were to redo this survey, I would have done four things differently. First, I would have asked if the participant could be contacted to further discuss their feedback. If they answered yes, they could insert their contact information. The purpose of this question would be to better understand their responses or clarify any questions they had. For example in Table 6.5 I could have possibly been able to clarify Participant 5's confusion and in Tables 6.7 and 6.8 I could have asked participants to provide more details about their suggestions.

Second, I would ask "Why?" for each Likert scale response. Since the response pool is so small, allowing participants to add up to a few sentences as to why they gave the rankings they did would eliminate poorly interpreting the results. Third, I would add a "N/A" option to the Likert scale questions. Doing so would allow participants who do not fit the necessary criteria of the question to excuse themselves from the results pool and not skew results.

Finally, I would have sent the survey earlier than scheduled for two reasons. First would be to allow more time for people to provide feedback and increase the response pool. Second, by sending the survey earlier, there would be time to send a second round survey that implemented the first round's feedback. A second round could yield more responses or provide more descriptive suggestions.

It is my belief that the negative reaction to the guideline does not detract from its value. Rather, this is due to a failure to properly communicate a context and purpose of the guidelines to the survey participants. Further, a larger pool of participants might produce a different result. One method to gather a larger pool of participants would be to publish this thesis in a research journal. By publishing this work, the guidelines would be subject to professional review.

8.2.2.1 Summary

The survey sample of seven is too small for any statistical analysis. Survey responses identified additional areas such as expressiveness, interactivity, and aesthetics. Finally, certain parts of the guideline were found by many participants to be of little value. The negative feedback is likely due to some miscommunication. It would be worth looking into the reason why participants with different areas of expertise had the same feedback.

8.3 Discussion for Hypothesis 2

Overall, I found it easy to test HAPI against my guidelines. Although I was unable to execute any of the suggested hardware testing guidelines, I could cover all other remaining, applicable chapters. Some guidelines were irrelevant for HAPI, but relevant for other SARs. This demonstrates the guidelines' versatility.

If I was given the opportunity to execute the guidelines against SARs again, I would want to ensure two things. First, I would want to ensure the feasibility of using multiple, different SARs when executing the guidelines. For example, SARs that use batteries, the IoT, or the Internet. By testing a variety of use cases, I would be able to see where the guidelines need improvement. Each iteration of the guidelines should make it more accessible to any type of SAR. By using only HAPI, I can only improve guidelines which apply to SARs similar to HAPI.

Secondly, I would want to ensure the feasibility of executing hardware testing guidelines by using one of the following two approaches. In the first approach, I would have five of the same SAR to undergo hardware testing. One SAR would undergo hazardous content testing, one SAR for battery tests, another for sound producing robots and locking mechanisms, and at least two for use and abuse testing scenarios, Chances are, depending on the SAR and its functions, it is possible to conduct multiple tests on the same robot. For example, abuse testing can be done on a SAR after finishing normal use testing. By doing so, the research can measure the difference between the two test cases. The second approach would be to test components of the SAR as opposed to the whole system. For example, if you wanted to test HAPI's antennae with tension and compression tests, you would need just half of HAPI's 'head' as shown by Figure 8.1. Note the cam used to move the follower (black antennae) is missing from the image. The knowledge I would gain from executing hardware

testing guidelines would enable me to make that chapter more user friendly in the next iteration.
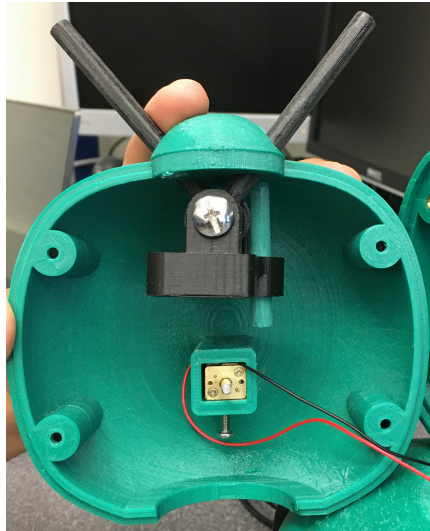
Figure 8.1: HAPI Antennae Configuration

Lessons learned from testing different SARs and from executing hardware testing would be turned into suggestions the researcher could refer to when modifying existing tests to apply to their SAR.

The next iteration of the guidelines needs a drastic improvement to the "Ethics and Human Computer Interaction" chapter. Currently, this chapter merely states Human Robot Interaction (HRI) concerns and ethical aspects of Child Computer Interaction (CCI). I found these generally helpful when assessing HAPI. Since there were no pass/fail measures, I instead made observations about HAPI. HAPI's use of Google's voice recognition opens up a larger discussion of ethics and privacy around voice recognition artificial intelligence (AI) software developed by multinational technology giants. On a much smaller scale, I could examine the approach HAPI uses when interacting with a child. HAPI's LED faces and programmed responses remain approachable, encouraging, and kind. As a result, HAPI passes this chapter since the interactions do not raise any ethical concerns. The next iteration of this guideline

would include additional suggested features, such as facial expressions, any imagery, and vocal responses.

Data Privacy is another chapter which was difficult to assess for HAPI. All data was stored on the attached cell phone and HAPI did not require the Internet. Similar to the ethics chapter, I noted possible concerns, without any pass/fail tests. The biggest concern was once again the use of Google's voice recognition software. While relevant, a discussion of data privacy concerns around this software remains out of the scope of this thesis. The next iteration of this chapter should have questions which make the researcher consider and acknowledge the data privacy risks within their system. While you can't fail an SAR for using a public voice recognition software, documentation should show an awareness of associated risks.

Overall, based on the guidelines, HAPI passes. HAPI does not fail any measure but has two items of potential concern. First, the sharp edges of the phone holder and the arm's inside edge require a second opinion, so as to be less subjective. Second, the hole in the back presents an electrical hazard and the risk of injuring a finger. A simple solution for this may be to cover the hole with clear packaging tape, which will still allow the user to see Raspberry Pi's light.

To make HAPI's assessment less subjective and identify additional improvements to the guidelines, further testing with more evaluators should be done. Using multiple people to asses the same SAR with the same guidelines would ensure inter-rater reliability. This approach can be used for any type of SAR as the feedback would further enhance the guideline.

The pass/fail approach worked for the guideline except for three chapters. I would recommend that along with a pass/fail rating, the user also states why. The evidence

would help support any argument in favor of accepting a questionable assessment, or foregoing the testing of an item or chapter.

The guideline can also be used with commercially available SARs. These types of SARs can fall into two categories: out of the box, or modified after purchase. If the SAR is out of the box, the guidelines assess the producer's capability. If modified after purchase, the guidelines ensure the SAR is still qualified.

8.3.0.1 Summary

HAPI passes the guidelines, but the way HAPI us designed means that the entire guideline could not be executed/tested. Guidelines and a pass/fail approach can be used for both designed and commercially purchased SARs. The next iteration should provide useful suggestions for improving the Ethics and Human Computer Interaction, and Data Privacy chapters.

Chapter 9

CONCLUSION

Principles from existing standards in different domains are used to craft guidelines for socially assistive robots (SARs). I extracted details from standards including the ASTM's Toy Safety Standard, the EU's Radio Equipment Directive, and ISO's Software Standard. I then provided experts in the field with a guideline summary and a survey questionnaire. The seven respondents overall were not very keen to use the guideline in their future work, and they enumerated missing considerations to incorporate in the guideline.

Had there been more time, the guideline would have been expanded to include more domains. The next iteration of the guideline should include chapters on interactivity and robotic movement. A second survey would be sent out to share updates from the first survey's feedback and perhaps yield more responses.

Evaluating the SAR guideline with one SAR demonstrated the guidelines' usefulness and limitations. I used a reading comprehension SAR called HAPI the Librarian for assessing my guidelines. For every item or chapter in the guideline, I determined if it as applicable to HAPI and whether the measure passed or failed. HAPI passed the guidelines.

The guideline's chapters, "Ethics and Human Computer Interaction (HCI)," and "Data Privacy" need to be updated to include relevant features that should be examined, and corresponding pass/fail measures where possible. A variety of SARs should be evaluated against the guideline to assess the application of those guidelines which were not applicable for HAPI. and hence, were not assessed.

The guideline lays initial groundwork for a SAR standard. The breadth of the guideline, currently and in the suggested next iteration, makes it applicable to SARs custom designed or purchased commercially.The guideline also provides test procedure recommendations and additional relevant standards

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.1 Appendix A

TABLE 5 Test Parameters for Use and Abuse Tests

Test	Age Category of Intended User, months	Numerical Value	
		Stated by the Voluntary Standard	Recommended for Toy Manufacturers
Drop test	0 to 18	10×4.5 ft ± 0.5 in. (137 cm)	4 ft, 6.5 in. (1.38 m)
	over 18 to 36	4×3.0 ft ± 0.5 in. (91 cm)	3 ft, 0.5 in. (0.93 m)
	over 36 to 96	4×3.0 ft ± 0.5 in. (91 cm)	3 ft, 0.5 in. (0.93 m)
Torque test	0 to 18	2 ± 0.2 in.·lbf (0.23 N·m)	2.2 in.·lbf (0.25 N·m)
	over 18 to 36	3 ± 0.2 in.·lbf (0.34 N·m)	3.2 in.·lbf (0.36 N·m)
	over 36 to 96	4 ± 0.2 in.·lbf (0.45 N·m)	4.2 in.·lbf (0.47 N·m)
Tension test	0 to 18	10 ± 0.5 lbf (44.5 N)	10.5 lbf (46.7 N)
	over 18 to 36	15 ± 0.5 lbf (66.8 N)	15.5 lbf (69.0 N)
	over 36 to 96	15 ± 0.5 lbf (66.8 N)	15.5 lbf (69.0 N)
Compression test	0 to 18	20 ± 0.5 lbf (89.0 N)	20.5 lbf (91.2 N)
	over 18 to 36	25 ± 0.5 lbf (111.3 N)	25.5 lbf (113.5 N)
	over 36 to 96	30 ± 0.5 lbf (133.5 N)	30.5 lbf (135.7 N)
Flexure test	0 to 18	10 ± 0.5 lbf (44.5 N)	10.5 lbf (46.7 N)
	over 18 to 36	15 ± 0.5 lbf (66.8 N)	15.5 lbf (69.0 N)
	over 36 to 96	15 ± 0.5 lbf (66.8 N)	15.5 lbf (69.0 N)

Figure .1: Test Parameters for Use and Abuse Tests

Refer to Number 1 ASTM Section 8 in .2.15 for full text.

.2 Appendix B: Social Robot Guidelines

This Appendix contains the Social Robot Guideline developed by the first hypothesis of this thesis. These guidelines serve as a pass/fail checklist with subsections dedicated to testing procedures.

.2.1 Hardware Safety

This subsection details the hardware safety requirements of a social robot.

.2.1.1 Physical and Mechanical Properties [1]

1. No "accessible, potentially hazardous sharp edges" or points

    (a) Sharp edges include: edges, holes, slots, and exposed bolt ends or threaded rods, nails, and fasteners

    (b) If the sharp edge is vital to the robot's function it must be properly labeled and undergo use and/or abuse testing to endure no hazard. The edge/point is protected by suitable means.

    (c) Wires and rods in the robot's interior "shall have their ends finished to avoid potentially hazardous points and burrs, shall be turned back, or shall be covered with smoothly finished protective caps or covers, if they can become accessible after use or reasonably foreseeable abuse"

2. Folding mechanisms and hinges do not contain a "possible crushing, laceration, or pinching hazard."

3. Robot and it's components (including cords, straps, and elastics) do not present a risk of "potential entanglement" or choking hazards [2].

4. When subjected to force, the SAR does not break or "distort at the risk of causing physical injury"

5. Robot surfaces must ensure that at "maximum and and minimum temperature of any accessible surfaces does not cause injury when touched"

.2.2 Hardware Testing

If keeping this section, add blurb about what 2.2 is about

.2.2.1 Hazardous Content

Refer to local, national, and/or international regulations and guidelines.

.2.2.2 Use and Abuse Testing

Refer to Number 1 ASTM Section 8 in .2.15 and amend as needed for a social robot. Normal use testing focuses on typical use while abuse testing tests extreme scenarios. ASTM Section 8 details tests for [1]:

1. Normal Use Testing 8.5

2. Abuse Testing 8.6

3. Impact Tests 8.7

4. Torque Tests 8.8

5. Tension Tests 8.9

6. Compression Tests 8.10

7. Flexure Tests 8.12

.2.2.3 Stalled Motor Test for Battery Operated Robot

1. Motors are tested with fresh batteries.

2. Refer to Number 1 ASTM Section 8.17 in .2.15 and amend as needed for a social robot.

.2.2.4 Tests for Robots Containing Secondary Cells or Batteries

Refer to Number 1 ASTM Section 8.19 in .2.15 and amend as needed for a social robot.

.2.2.5 Tests for Robots that Produce Noise

Refer to Number 1 ASTM Section 8.20 in .2.15 and amend as needed for a social robot.

.2.2.6 Tests for Locking Mechanisms or Other Means

Refer to Number 1 ASTM Section 8.26 in .2.15 and amend as needed for a social robot.

.2.3 Battery Operated Robots [1]

In this subsection a battery includes chargeable and nonchargeable batteries.

1. Battery compartments are properly labeled and "shall not be accessible, before or after testing without the use of a coin, screwdriver, or other common household tool".

2. "The maximum allowable direct current potential between any two accessible electrical points is 24 V nominal."

3. "Batteries of different types or capacities shall not be mixed within any single electrical circuit."

4. "The surfaces of the batteries shall not achieve temperatures exceeding 71°C."

5. The robot does not present a "combustion hazard."

6. Design guideline (Annex 8): "The design of airtight products shall allow the gas emitted by the battery to be absorbed or to escape if the amount of gas emitted is significant enough to present an explosion, combustion or over-pressure hazard."

7. For lithium-ion batteries refer to Number 1 ASTM Section 4.25.11 in .2.15 and amend as needed.

.2.4   Flammability [2]

1. "Materials other than textiles shall not be flammable"

2. "Must provide adequate protection against fire hazards"

3. For Flammability Testing refer to Number 1 ASTM Annex 5 in .2.15 and amend as needed.

.2.5 Chemical Properties

Best to refer to local, national, and/or international regulations for up to date and precise hazardous substance regulations.

1. Material substances shall not not be "toxic, corrosive, or an irritant," especially in contact with the user [1].

.2.6 Hygiene

1. Surfaces must be "visually clean" and "meet hygiene and cleanliness requirements in order to avoid any risk of infection, sickness or contamination"

.2.7 Sound Producing Social Robots

This subsection does not cover social robots attached to sound producing devices such as cellphones and laptops.

1. For close to the ear robots, A-weighted sound intensity shall not exceed 65 dB.

2. For close to the ear robots, C-weighted sound intensity shall not exceed 110 dB.

3. For all other robots, A-weighted sound intensity shall not exceed 85 dB.

4. For all other robots, C-weighted sound intensity shall not exceed 115 dB.

.2.8 Electrical Properties

1. If in contact with children, a social robot that operates "from nominal 120V branch circuits shall conform to 16 CFR 1505 (Requirements for Electrically

Operated Toys or Other Electrically Operated Articles Intended for Use by Children)[2].

2. Robot "shall not be powered by electricity of a nominal voltage exceeding 24 volts direct current (DC) or the equivalent alternating current (AC) voltage, and their accessible parts shall not exceed 24 volts DC or the equivalent AC voltage [1]."

3. Where applicable, the robot provides protection against electric shock or other electrical hazards.

4. The robot must be designed and manufactured in such a way that [1]:

   (a) Any and all radiation generated is "limited to the extent necessary for the operation of the [robot], and must operate at a safe level in compliance."

   (b) the [robot] "operates safely even when the electronic system starts malfunctioning or fails due to failure of the system itself or an outside factor."

.2.9 Radio Equipment

This subsection details standards for radio equipment used within the social robot.

.2.9.1 Off The Shelf Parts

If the social robot uses commercial, off the shelf parts, these components already comply with national and international standards.

.2.9.2 Original Parts

For non-commercial parts refer to the technical rules and operating conditions of your origin country.

.2.10 Electromagnetic Compatibility

This subsection details standards for electromagnetic equipment used within the social robot.

.2.10.1 Off The Shelf Parts

If the social robot uses commercial, off the shelf parts they already conform to national and international standards.

.2.10.2 Original Parts

For non-commercial parts refer to the technical rules and operating conditions of your origin country.

.2.11 Software Quality

This subsection is developed using the Consortium for Information and Software Quality's Common Weakness Enumeration (CWE) document [42]. The CWE identifies code targeting weaknesses in security, reliability, performance efficiency, and main-

tainability of software. For an in-depth software quality standard, refer to Number 2 Chapters 6, 7, and 8 in Section .2.15 [41].

.2.11.1 Maintainability

Refer to Table 1 in Number 3 in Section .2.15.

.2.11.2 Efficiency

Refer to Table 2 in Number 3 in Section .2.15.

.2.11.3 Reliability

Refer to Table 3 in Number 3 in Section .2.15.

.2.11.4 Security

Refer to Table 4 in Number 3 in Section .2.15.

.2.12 Internet of Things Security

An Internet of Things (IoT) ecosystem interconnects "web enabled smart devices" and is vulnerable to hacking [43].

.2.12.1 Common Challenges

Social robots that use IoT should be aware of vulnerabilities from the following sources [44]: (To Do: remove word-for-word of this list)

1. Software and Firmware Vulnerabilities

    (a) Lack of computational capacity for efficient built-in security

    (b) Poor access control in IoT systems

    (c) Lack of regular patches and updates due to limited budgets and technical limitations of IoT devices.

    (d) Users may not update their devices, thus restricting vulnerability patching

    (e) With time, software updates might be unavailable for older devices

    (f) Poor protection from physical attacks

2. Insecure Communications

3. Data Leaks from IoT Systems

    (a) Data transferred and stored in the cloud and cloud hosted services

    (b) third party services

4. Malware Risks

5. Cyber Attacks

    (a) Denial of Service attacks

    (b) Denial of Sleep attacks

    (c) Device spoofing

    (d) Physical intrusion

    (e) Application based attacks

.2.12.2   Suggested Security Measures

The most common IoT security measures are [45]:

1. Authentication

2. Encryption

3. Trust Management: Detect and eliminate malicious nodes and to provide secure access control

4. Secure routing for sensors and actuators

5. Use of New Technologies

6. Prevent data leaks by enabling encryption and service communication protocols and/or only collecting necessary data [44].

.2.12.3   Relevant IEEE Standards

For additional reading:

1. 2410-2021: Biometric Privacy

2. 2413-2019: Architectural Framework for the Internet of Things

.2.13   Ethics and Human-Computer Interaction

Human-computer interaction, (HCI), focuses on interactions between humans and computers. For child-computer interaction, (CCI), the term child defines any individual under the age of 18 years old, and follows a similar scope to HCI.

.2.13.1   Concerns of Human-Robot Interactions [3]

1. Humans and Robots ethical concerns

(a) Robot replacement of humans (expand on this scope with SR with prof's help)

(b) Minimize risks when humans are engaging with robots - in close contact with humans, any possible jeopardy must be anticipated and minimized

(c) Human psychology towards robots

2. Privacy

3. Individual Differences

(a) Individual differences include cultural differences, indigenous people, age group differences, physical impairment and disabilities. Be aware of individual differences when designing a SAR.

.2.13.2 Ethical Spheres of CCI [4]

1. Formal Procedural Research

(a) Refer to standardized formal research procedures

2. Design Ethics

(a) Explores impact of technology and society

3. Everyday Ethics

(a) Explores ethical concerns in daily life and social interactions between people without an explicit link to technology.

4. Teaching Design Ethics

(a) Functioning as a learning goal, this form of ethics aims to raise awareness of technology's impact on society.

5. Teaching Everyday Ethics

   (a) Functioning as a learning goal, this form of ethics aims to teach children to act ethically

.2.14   Data Privacy

.2.14.1   Region Specific Data Privacy Established Standards

Data privacy standards to be aware of if operating in the United States:

1. Children Online Privacy Protection Act (COPPA)

2. Health Insurance Portability and Accountability Act (HIPPA)

3. If operating in California

   (a) California Consumer Privacy Act (CCPA)

Data privacy standards to be aware of if operating in the European Union

1. General Data Protection Regulation (GDPR)

.2.14.2   Basic Data to be Kept Private [5]

1. Basic Identifying Information

2. Web Data

3. Health and Genetic Data

4. Racial or Ethnic Data

.2.15   Additional Guidelines/Resources

1. ASTM Standard Consumer Safety Specification for Toy Safety

2. ISO 5055 Automated Source Code Quality Measures

3. CISQ Common Weakness Enumeration

4. RoHS

5. UL Plugs

.3 Appendix C: SAR Recruitment Email

This Appendix contains the text sent to SAR experts asking them to take part in the survey shown in .4

INFORMED CONSENT TO PARTICIPATE IN A

RESEARCH PROJECT:

"Design Guidelines for Social Robots"

This form asks for your agreement to participate in a research project on the design of socially assistive robotics (SAR). Your participation involves taking a survey, and it is expected that it will take approximately 15 minutes. There are minimal risks anticipated with your participation. Those in the field of SAR may benefit from your participation. If you are interested in participating, please review the following information:

The purpose of the study is to examine design considerations used in creating or selecting SAR systems. Potential benefits associated with the study include the development of a guideline for designing SAR. This may benefit new practitioners in the field of SAR.

If you agree to participate, you will be asked to complete a brief (10–15 minute) survey, which will ask you questions regarding your demographic information, perspectives on SAR systems, and perspectives on an SAR design guideline developed

by the research team.

You will be asked to provide demographic information. Because the study consists primarily of survey data collection from a non-vulnerable population, the associated risk is low. It is possible that participants may be subject to loss of confidentiality. If participant data become available, they may suffer harm. Participant data include demographic information. To minimize risk of loss of confidentiality, all study documents (paper) will be kept behind two locked doors in the PI's office. All digital documents will be stored on a password-protected hard drive in the PI's office. Your data will be stored by the PI until five years post study termination (September of 2028). Your data will be destroyed at anytime upon your request, and with no penalty.

Please be aware that you are not required to participate in this research, refusal to participate will not involve any penalty or loss of benefits to which you are otherwise entitled, and you may discontinue your participation at any time. You may omit responses to any questions you choose not to answer. There are minimal risks anticipated with your participation in this study, as your survey responses will be collected anonymously.

This research is being conducted by Dr. Eric Espinoza–Wade in the Department of Mechanical Engineering at Cal Poly, San Luis Obispo. If you have questions regarding this study or would like to be informed of the results when the study is completed, please contact Dr. Espinoza-Wade at `erwade@calpoly.edu` or 617-308-0498.

If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Michael Black, Chair of the Cal Poly Institutional Review Board, at (805) 756-2894, mblack@calpoly.edu, or Ms. Trish Brock, Director of Research Compliance, at (805) 756-1450, pbrock@calpoly.edu.

If you are 18 or older and agree to voluntarily participate in this research project as described, please indicate your agreement by completing the survey. Please keep a copy of this form for your reference, and thank you for your participation in this research.

This Appendix contains the text of the Google Forms survey sent to SAR experts. CONSIDER either updating the questions on latex for the "prefer not to respond" OR to insert screenshots of the Google Form.

SAR Survey

Demographics

1. Age

    - <25

    - 25-34

    - 35-44

    - 45-54

    - 55-64

    - >65

    - Prefer not to respond

2. Gender

    - Female

    - Male

    - Transgender

    - Non-binary

    - Prefer not to respond

3. Profession

- Researcher in academia

- Researcher in industry

- Other

4. Area of expertise

- _____

5. Years in the SAR field

- <5

- 6-10

- 11-15

- 16-20

- 20-25

- >25

6. Your target population of interest

- Children (neurotypical)

- Children (impaired)

- Adults (neurotypical)

- Adults (impaired)

- Other

7. The social robots/agents you use are

- Purchased commercially

- Designed

- Prefer not to respond

8. If you design social robots/agents, primary considerations are:

  - Aesthetics

  - Functionality

  - Safety

  - Interactivity

  - None of the Above

9. How do you assess suitability of your SAR system prior to deploying with humans?

  - _____

There are no existing standards that describe critical factors for the design of social robots. However, existing standards (e.g., toy safety, electrical devices) contain design considerations relevant to SAR systems.

Consideration	Characteristics
Hardware Safety	Physical / mechanical properties
Hardware Testing	Hazardous content, Use/abuse testing, Motor testing (battery operated), Noise testing, Locking mechanisms
Battery Operated	Flammability, Chemical properties, Electrical properties, Hygiene, Sound producing systems
Software Quality	Maintainability, Efficiency, Reliability, Security
Electromagnetic Compatibility	Off the shelf components, Original components
Radio equipment	Off the shelf components, Original components
IoT Security	Common challenges, Security measures, Relevant IEEE standards
Ethics	HRI concerns, ACM/CCI ethics

Table .1: Social robot design guidelines

SAR design guideline

1. Are any design considerations missing from the table?

   - Yes

   - No

2. If yes, list missing considerations

   - _____

3. Are any design considerations in the table unimportant to you?

   - Yes

   - No

4. If yes, list unimportant considerations

   - _____

Question	Not at all 1		2	3	4	5	6	Highly 7
If you design SAR systems, how likely are you to use this guideline?	☐		☐	☐	☐	☐	☐	☐
If you purchase SAR systems, how likely are you to consider this guideline in selecting a new system?	☐		☐	☐	☐	☐	☐	☐
If you teach about SAR systems, how likely are you to use this guideline in instruction?	☐		☐	☐	☐	☐	☐	☐

.5 Appendix E: SAR Survey Survey Responses

This Appendix contains the survey responses from SAR experts in the field.

Participant Number	Age	Gender	Profession	Area of Expertise
1	25-34	Female	Independent scholar	Human-robot interaction, child-robot interaction, education, language learning
2	Prefer not to respond	Prefer not to respond	Researcher in academia	Socially aware AI
3	25-34	Female	Researcher in academia	Human-robot interaction
4	25-34	Male	Researcher in academia	Design, human-robot interaction, minimal robots, speech interaction
5	35-44	Male	Researcher in government	Human Factors Psychology
6	25-34	Female	Researcher in academia	Social psychology
7	25-34	Male	Researcher in academia	Machine learning, robotics, autonomous driving, opinion evolution dynamics

Participant Number	Years in SAR field	Your target population of interest	The social robots/agents you use are	If you design social robots/agents, primary considerations are:	How do you asses suitability of your SAR system prior to deploying with humans?
1	6-10	Children (neurotypical)	Designed	Aesthetics, Functionality, Safety, Interactivity	Feedback and testing with all stakeholders - e.g. children, parents, educators, researchers
2	16-20	Adults (neurotypical)	Purchased Commercially	Functionality, Interactivity	use students before using people
3	11-15	Children (neurotypical and impaired) Adults (neurotypical and impaired)	Designed	Aesthetics, Functionality, Safety, Interactivity	Look over and test capabilities
4	6-10	Adults (neurotypical)	Designed	Functionality, Interactivity	Wizard-of-oz testing
5	< 5	Adults (neurotypical)	Designed	Functionality	I'm not really sure what you mean by "suitability" here. From a safety standpoint, in our embodied robot studies, we do not allow human participants to be in close proximity to the robots, reducing the likelihood of potential injury.
6	6-10	Adults (neurotypical)	Purchased Commercially	Functionality, Safety, Interactivity	Since we usually buy available robtos we heavily rely on previous experiences of colleagues.
7	< 5	Adults (neurotypical and impaired) Basically I am interested in assistive robots for everyday purpose	Purchased Commercially	Functionality, Safety, Interactivity	This is a good question. I think one way to assess suitability is doing pilot/full experimental studies with participants (in line with the intended end user). Measure different responses both quantitative (like Heart rate, galvanic skin response, EEG (maybe)) and qualitative (like NASA TLX form, likert scale questionnaire (tailored for the study)). Then compare with a baseline and prove that the SAR is helpful to improve some performance measure. If we are concerned about the safety, then it has to come at the design phase and also pre-pilot/experiment stage where we as researchers test out the safety in both usual scenarios and also in edge case (very important to test for safety in the edge cases).

Participant Number	Are any design considerations missing from the table?	If yes, list missing considerations otherwise state "N/A"	Are any design considerations in the table unimportant to you?	If yes, list unimportant considerations otherwise state "N/A"
1	Yes	Software - Privacy, Usability; overall system: interactivity, usability, fluidity	No	Na
2	No	N/A	Yes	hardware safety
3	Yes	expressiveness, sensing, degrees of freedom	Yes	radio, electromagnetic, iot security
4	Yes	Interactivity, data requirements	No	N/A
5	No	N/A	No	N/A
6	No	N/A	No	N/A
7	Yes	Edge case testing. Maybe aesthetic because a SA robot has to be accepted/trustable by the intended end user.	No	N/A

Participant Number	If you design SAR systems, how likely are you to use this guideline?	If you purchase SAR systems, how likely are you to consider this guideline in selecting a new system?	If you teach SAR systems, how likely are you to use this guideline in instruction?
1	1	1	1
2	1	2	2
3	1	1	1
4	3	3	3
5	6	2	6
6	4	6	6
7	7	7	7