Exploration of Human Reactions to a Humanoid Robot in Public STEM Education

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***Abstract*— Humanoid robots have become a hot topic for robot design in the service and entertainment industry. However, there is a gap between humans' rich virtual exposure to humanoid robots through the media and their actual interaction experiences with them. To provide research support for humanoid robot design, the present paper explored the behavioral pattern of humans, dialog themes, and emotional responses in interaction with a humanoid robot that is capable of face recognition and conversations at two public settings: a park (50+ people) and a charter school (about 360 people). Results showed that major interaction activities of the adult dominant group at the park included looking at the robot, talking to the robot, talking to others about the robot, and taking photos. Children at the school did similar activities except taking photos, and they showed strong desire to interact with the robot and rich emotional responses. Major dialog input themes from the participants included greeting, asking about the robot's identity (e.g., age, origin), testing the robot's knowledge and capabilities, talking about preferences and opinions, and correcting the robot's conversation errors. Observed emotional responses included liking, surprise, excitement, fright, frustration, and awkwardness. Overall, the children showed more positive emotions than negative emotions. The study provided evidence that adults and children interact with the humanoid robot the way they interact with other humans, and it provided evidence supporting the uncanny valley effect. Future research will explore more populations and seek more rigorous research methods.**

Keywords— humanoid robot; children; public STEM education; human-robot interaction

I. INTRODUCTION

Humanoid robots have become a hot topic for robot design in the service and entertainment industry. Considering this trend, it is likely that today's children will be a group of people who use robots regularly in the next 20-30 years. Their interest and exposure to robots will have a great impact on the robot industry. This trend is further evidenced by the US Government's inclusion of robotics in its efforts to promote STEM education in the United States. People have had exposure to humanoid robots since the 20th century through movies (e.g., Metropolis in 1927; Bicentennial Man in 1999; The Stepford Wives in 2004; Ex-Machina in 2015), TV shows (e.g., Small Wonder in the 1980s; Humans in 2015), and YouTube videos (e.g., Geminoid DK & Ishiguro). However, people rarely have experiences of interacting with a humanoid robot face-to-face. There is a great need for research on how humans interact with humanoid robots to support the practice of designing humanoid robots.

The current humanoid robot project provides opportunities to educate adults and children about science and engineering through actual interaction with a humanoid robot. This research provides evidence to answer the following research question: How do humans behaviorally, verbally, and emotionally interact with a humanoid robot in public environments?

II. LITERATURE REVIEW

A. Human Computer Interaction and Anthropomorphism

Reeves and Nass found that humans tend to interact with their computers the way they interact with other humans [1]. Therefore, it is reasonable to predict that humans will interact with a humanoid robot in a similar way to how they interact with other humans.

Espley, Waytz and Cacioppo [2] proposed a three-factor theory that can be used to predict when people are likely to anthropomorphize a robot and when they are not: (a) The availability of knowledge of anthropomorphism, (b) the motivation to make sense of the behaviors of a robot, and (c) the need for social connection. These three factors are not difficult to find in human interactions with a humanoid robot. First, the human-like appearance of a humanoid robot boldly suggests to a human viewer, in a way that a non-humanoid robot may not, that the robot will behave in a human-like manner. Second, humans have a natural tendency to try to make sense of the world. Even though many people today have few experiences interacting with humanoid robots, interacting with other humans is an everyday occurrence. It is natural to transfer knowledge of interactions with other humans to interactions with a robot made to resemble a human. This forms a backdrop in which to assimilate and accommodate new, nonhuman, robot behaviors into the existing knowledge system of human-human interaction experiences. Third, according to the self-determination theory [3], humans have an inborn nature to connect with social contacts. If this is the case, it is not difficult for humans to anthropomorphize a humanoid robot to make this connection. Therefore, it is hypothesized that humans will, by default, interact with a humanoid robot like interacting with another human. This may include showing a range of emotional reactions such as pleasure at meeting a

new acquaintance, confusion and awkwardness at lack of understanding or communication failure, and antagonism, if social relationships are strained, for example, by bragging.

B. *Children and Robots Interaction*

There has been some research on human interaction with a humanoid robot [4]. Related research [5] on using robots in autism research mainly focuses on behaviors that increase and maintain children's engagement in interacting with the robots, such as eye-to-eye gaze. Engagement is not only an issue for autistic children, but for public interest in STEM education.

Investigating the reactions of normal children and adults to a robot dog at a shopping mall [6] showed that children developed positive emotions toward the robot dog at the visceral level, at the behavioral level, and at the reflective level. The children became excited when they first saw the robot dog, then they played with the robot dog, and they expressed the wish to bring the dog home. However, a robot dog has much fewer potential functions than a humanoid robot, and plays a significantly different role from a humanoid robot. It is expected that children would react differently to a humanoid robot from a robot dog. It is hypothesized that children will also interact with a humanoid robot in a way that is similar to how they interact with other humans.

C. *Uncanny Valley*

The uncanny valley effect is a phenomenon whereby a human's liking of a robot increases as the robot's resemblance to a human increases, up to a point. When a robot (or other human likeness, such as a cartoon or painting) closely resembles a human yet differs in some barely noticeable way, the human's liking of the robot suddenly drops and is replaced by a feeling of extreme dislike [7]. The turning point may vary across populations, but it is likely to observe negative emotions toward a humanoid robot if its human likeness falls in this close, but imperfect, range.

The purpose of this research is to explore human-robot interaction in public settings through three aspects: (1) The human behavioral patterns, (2) human dialog text, and (3) human emotional responses to a humanoid robot during interaction.

III. METHOD

The current paper consists of two parts: an informal preliminary observation at a park picnic and a formal study at a charter school, both at an eastern city in the US. Without statistical measures, the observational data collected at the park were not intended for research and generalization, rather to develop a rubric to facilitate quantitative data collection for the second study at a charter school. However, the actual arrangement at the school turned out to be so different from the park that the researchers developed a new rubric.

A. *The Humanoid Robot "KEN"*

KEN is a humanoid robot made from a mannequin upper body and head, with built-in computers. He detects faces and learns to recognize the people he meets. He can carry on a conversation with a human. KEN can move his neck horizontally or vertically, which allows for face tracking and human-like head gestures. A picture of KEN is shown in Fig. 1 and more information can be found in this website: http://sites.ieee.org/encs-humanoid/

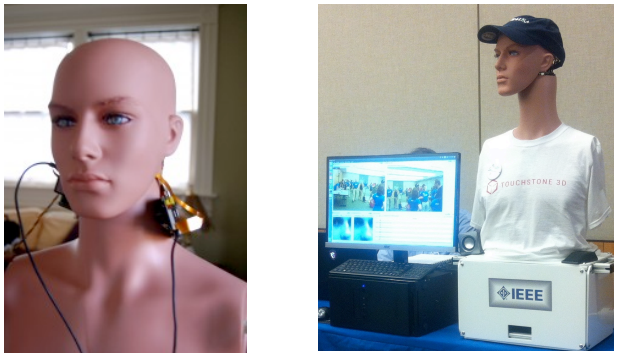

Fig. 1. Humanoid robot KEN (left photo by Kiko McDonald, under testing at a workplace; right photo by Lixiao Huang, normal setup for demo)

1) Vision. KEN has authentic blue eyes. KEN is constantly searching the video image frames from his eye cameras for human faces. He moves his head to center a face in his gaze. In the background, he records information about the faces he sees to allow him to recognize the face again and to associate the face with a name. The computer monitor shows the scenes KEN sees through his eye cameras, as well as identified faces.

2) Speech. KEN uses voice activity detection and speech recognition to record spoken phrases and translate them to text. The artificial intelligence system based on the ALICE chatbot processes the text into a response, which is spoken back using the eSpeak text to speech synthesizer. KEN has a speaker embedded in his chest. He hears through a microphone on the table or a cell phone receiver. When the background noise is low, the audience can speak directly standing in front of KEN. When there is a certain level of noise, the audience needs to pick up the microphone on the table to speak to KEN. Voice activity detection is done by a naïve sound intensity threshold algorithm. Manual voice activity detection is possible for acoustically challenging environments by using either a cell phone app or manually unmuting and muting the microphone. Speech to text conversion is performed by the Google Web Speech API. The computer monitor shows the transcribed text KEN receives from the audience and the machine generated responses that he speaks.

B. *Data Coding*

All codings used the data-driven method [8], in which the categories were created based on what was observed from the interaction. The three types of codings are:

1) Behavioral pattern coding. The major interaction activities the audience engaged in with the humanoid robot KEN were coded, or example, looking at the robot or talking to the robot.

2) Dialog text coding. When people speak to KEN, his voice activity detection and speech recognition translate speech into text. Then he generates a text response which he says to the audience using a synthesized voice. The transcribed dialog text is stored in KEN's computer. Only dialog text from humans was analyzed, using the verbal data analysis method [9], to get the dialog input themes of humans talking to a humanoid robot, for example, greeting, asking about name, hobby, origin, and language.

3) Emotional response coding. The emotional responses were coded from observation of the audience at the site as they interacted with the humanoid robot KEN, for example, liking, excitement, fright, and curiosity.

IV. Observation 1: At a Park Picnic

The first observation took place at a community outreach event of a local professional organization in summer 2015: a 4-hour picnic at a park. The participants were instructed to eat BBQ first and then come to interact with KEN. The food was constantly available and people were free to leave at any time.

A. Participants

About 50-70 people attended the event, including members of the sponsoring organization and their families and friends. Observation notes recorded 22 people's interactions with the robot. The participants included males and females; white, Asian, black or south African; estimated age from 3 to 70; children, high school students, college students, graduate students, young professionals, and senior professionals. Their social units included individuals, father and son, mother and son, father and daughter, a family of three or four, adults with their older parents and son, and friends.

B. Procedure

The humanoid robot KEN and the computer monitor were set up ahead of the event. When people approached the robot, a robot developer introduced KEN's abilities to see and converse, and he gave a quick demonstration of speaking to the robot KEN. Depending on the background noise level, the demonstration involved directly talking to KEN or talking through the microphone held in hand. Then the audience took over and interacted with the robot for different lengths and in various ways that naturally occurred. The observation started when people began approaching the robot.

C. Results

1) Behavioral pattern. The categories of the observed behavioral pattern are listed in Table I.

TABLE I. Behavioral Categories

Categories	*Notes*
Talking	• Talking to KEN directly to the face • Talking to KEN via the cell phone • Talking to KEN via the microphone held in a hand • Explaining to one's company what KEN is doing • Making comments about KEN when thinking aloud - e.g., when a man talked to KEN and KEN did not respond correctly, the man said to himself while looking at KEN, "He does not know how to respond." • Making comments about KEN to others • Discussing about KEN within a small group standing nearby • Asking the developer questions about KEN • Encouraging others to talk to KEN
Looking	• Looking at KEN waiting for response • Looking at the back of KEN • Looking at the inside of KEN • Looking at the computer monitor of what KEN sees • Looking around for the next interested person to pass on the microphone • Looking at other people (strangers, family, or friends) interacting with KEN and listening to their dialogs
Taking photos	• Taking photos of KEN • Taking photos with KEN

The length of direct engagement with KEN was normally less than 5 minutes. Communication with the developer and watching others interacting with KEN could reach 15 to 20 minutes. Many people approached KEN multiple times.

2) Dialog themes. The transcribed dialog text included 166 input records from the audience, as well as 78 times face recognition commands sent from the internal AI system. The dialog input themes included greeting, self-introduction, testing KEN's capabilities (e.g., math, telling a joke), asking about facts about KEN (e.g., name, age, preference of food, and opinions on politics), see Table II.

TABLE II. Dialog Themes

Categories	*Notes and Examples*
Greeting	• First contact - e.g., "Hello", "Hi" • Farewell - e.g., "See you again have to go."
Asking about KEN's identity	• Name - e.g., "What is your name?" • Age - e.g., "How old are you?" • Hobby - e.g., "What is your hobby?" • Origin - e.g., "Where are you from?" • Language - e.g., "Do you speak German?" • Experiences - e.g., "Have you been to the beach?" • Friend - e.g., "Who is your best friend?"
Self-introduction	• Self-introducing things they asked KEN about: name, hobby, preferences, etc. • "My name is [Maria]."; "I build robots."; "My favorite food is oatmeal."
Asking KEN's opinions	• "How do you feel about…?"; "Can you tell me a little bit about…?"; "What is life?" • E.g., Java, politics, life, etc.
Asking KEN's preference	• "Do you like…?"; "What kind of…do you like?"; "What is your favorite…?" • E.g., food, movie, pattern, and sport.
Testing Ken's knowledge and capability	• Recognizing color - e.g., "What color is my hat?" • Calculation of math - e.g. "What's two plus two?" • Telling a joke - e.g., "Can you tell a joke?" • Memory - e.g., "I have seen you before, do you remember me?" "Do you recognize me?" • Dreaming - e.g., "What do you dream about?"
Correcting KEN	• Correction included name, color, etc. • E.g., "No you've got me confused I'm [Tom]"; "No, it is beige."
Comments and Teasing	• Expressing emotion, e.g., "We love you." • Teasing - e.g., "You look a lot like a fellow named Ken."

Using the verbal data analysis method resulted in a frequency pattern of the dialog themes in Fig. 2. Greeting, self-introduction of name, talking about preferences and opinions, and testing KEN's capabilities were the most frequent dialog themes.

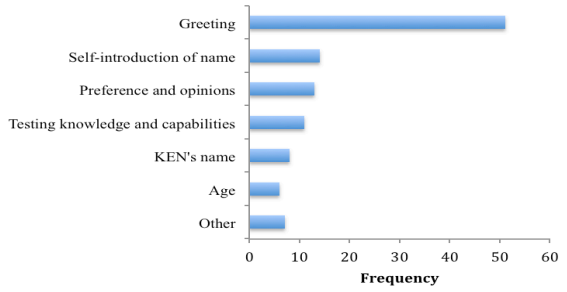

Fig. 2. Dialog themes from the audience at the park

3) Emotional responses. The observer noted a variety of emotions based on facial expression, behavior pattern and dialog text (see Table III).

TABLE III. EMOTIONAL RESPONSE CATEGORIES

Categories	*Notes and Examples*
General affect	• Interacting with the robot indicated liking • Their smiling facial expressions showed positive emotions.
Excitement	• Positive comments - e.g., "This is so interesting" • Risen eyebrows, opened mouth, cheerful smile
Curiosity	• Asking questions about the robot • Checking the inside of the robot
Intimidation	• Comment - e.g., "the robot looks creepy" • A child dared not to talk to the robot directly but asked his dads to talk to the robot.
Annoyance/ awkwardness	• When the robot failed to hear the input correctly, male adults showed annoyance, and female adults showed awkwardness.
Frustration	• When robot repeatedly failed to recognize faces correctly or say names correctly, some people showed frustration.

V. OBSERVATION 2 : AT A SCHOOL

The second observation was conducted at a charter school. The event took place from 10am to 2pm, divided into seven time slots. The teachers in each grade signed up for one time slot and brought the entire grade level to a large multipurpose room where KEN was located. Kindergarten through third grade signed up for 20-minute slots. Fourth through seventh grades signed up for 40-minute slots with a more in-depth presentation. The final presentation slot combined sixth and seventh grades. The demos for each group were arranged back-to-back with a five-minute transition between groups. The teachers of each group repeatedly instructed their students to be quiet throughout the event.

A. Participants

A total of 360 children from kindergarten to 7th grade participated in the event, along with 21 teachers (approximately three teachers for each grade level). The number of students for each grade level is listed in Table IV. The major race categories of the children included white and black or African American. Gender appeared to be distributed evenly.

TABLE IV. PARTICIPANTS' GRADE LEVEL, AGE, AND NUMBER

Time	*Grade Level*	*Age*	*Number*
10:00-10:20	First grade	6-7	50
10:25-10:45	Third grade	8-9	50
10:50-11:10	Kindergarten	5-6	40
11:15-11:35	Second grade	7-8	50
11:40-12:20	Fourth grade	9-10	55
12:25-13:05	Fifth grade	10-11	50
13:10-13:55	6th/7th grade	11-13	65

B. Measures

The data sources for this study included three sources: (1) Handwritten observation notes including questions asked and physical and emotional reactions to the robot; and (2) transcribed dialog input text - what KEN actually perceived and how he responded.

C. Procedure

The robotics team set up KEN at a table adjacent to the west wall and projected a computer screen to the east wall. At the beginning of each time slot (see Table IV), teachers brought in children and let them sit at the center of the room, facing the east wall. First, the robot team leader greeted the children and went through the following steps: (1) Asking a few questions, including what do engineers do and what do engineers build, (2) showing a 90 second YouTube video introducing what engineers do, (3) showing a YouTube video of a self-driving car that the robot team leader worked on before (this step was only for 4-7th graders), (4) directing attention to the humanoid robot KEN. Questions were accepted from the audience during these steps.

Second, the children were asked to turn to face KEN at the west wall and the robot developer went through the following steps: (1) Briefly introducing KEN, (2) demonstrating speaking to KEN, (3) using two American Girl dolls (Emily & Liberty) to demonstrate face recognition and ask the students the difference between a doll and a robot, (4) asking volunteers to come up to talk to KEN, one person at a time, and (5) answering more questions from the audience.

D. Results

1) Behavioral pattern. The behavorial pattern consisted of greeting, volunteering, and reacting to KEN's performance and the presenter's information about KEN (see Table V).

TABLE V. CHILDREN'S BEHAVIORAL PATTERNS DURING INTERACTION

Categories	*Notes and Examples*
Greeting	• Waving one hand or two hands to KEN when first met KEN, saying "Hello/Hi KEN"
Asking questions	• During the whole event, students consistently raised hands to ask questions. When not picked, they raised again. • At the end of the session, still more than half of the students raised hands to ask questions, but time only allowed a small number to speak up.

Categories	*Notes and Examples*
Interacting with KEN	• When they were asked to have someone volunteer to talk to KEN, everybody raised their hands up high. • A fourth grade student begged to let him try, saying, "Please, please, let me try it. I love robots!" • A second grade boy said, "I got this.", and stepped in front of KEN before he was called to come up. • When it was time to leave, each group had more than 10 students who got up and stood in front of KEN, either talking to KEN or just looking around KEN and the computer monitor until their teachers urged them to leave; some students waved hands at KEN and trying to get KEN's attention when they were lined up to leave.

2) Dialog themes. The dialog data consisted of two sources during the event: (1) Dialog text of the conversation with KEN stored on KEN's computer (see Fig. 3), including 155 input items; and (2) questions for the presenters (see Table VI).

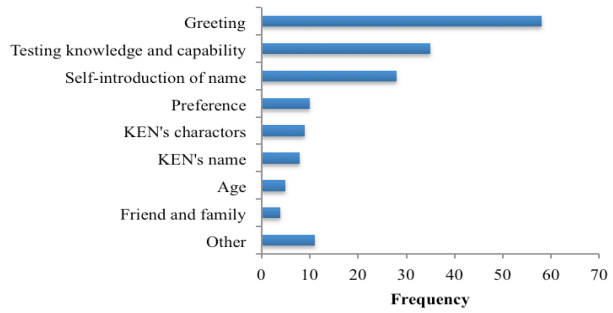

Fig. 3. Dialog themes from the audience at the charter school

TABLE VI. CHILDREN'S QUESTIONS ABOUT THE ROBOT BY GRADE

Questions	*K*	*1*	*2*	*3*	*4*	*5*	*6/7*
How long does it take to build/program a robot?	x			x			x
Why does he not have legs? Where are his arms? Why didn't you build legs?	x		x	x			
How did you make it [the robot]?	x						
Can he laugh at jokes? Does he know any jokes?		x					x
What is he made of?		x					
How can he move his head? How do you make the robot move?			x				
Would the robot become too hot if there is a computer running inside?			x				
Does he know math?			x				
How does he memorize things?			x				
How does he know what is the Internet?				x			
Is it a prototype? Are you going to make another one?				x			
What is the purpose of making it?				x		x	
How does it take pictures of us?					x		
If you program the robot, what programming language do you use?					x		
How did you come up with his name? What does KEN mean?						x	x
Is there anything on his chest? Can you lift up his shirt?						x	
How did you make the voice inside? Can you change his voice? How did you build him to talk?						x x	
What is a good way to start to be an engineer?						x	
If you ask silly questions, will he answer or get confused?							x
Is there an ear on KEN?							x
How far can KEN hear?							x
Is KEN aware of his gender?							x
Does KEN know about Siri?							x

3) Emotional response coding. Children showed strong emotional responses during the event (see Table VII). A few critical moments included: (1) Introducing KEN's camera embeded eyes, (2) showing KEN's math ability, (3) when KEN failed to respond appropriately, and (4) when KEN said something interesting. Emotional responses included emotion related behavors and emotional comments about KEN.

TABLE VII. EMOTIONAL RESPONSES OF THE STUDENTS AT THE SCHOOL

Categories	*Notes and Examples*
Liking	• Several fourth grade shouted, "I love robotics" • A third grade child said, "I will miss you KEN"
Excitement	• Evidences for excitement: (1) loud sound by clapping, laughing, and shouting, "Wow", "That's very cool!", and "Awesome!"; (2) opening mouths, widening eyes, raising eyebrows, and hands holding their faces; (3) actively volunteering to talk to KEN by raising hands up high, and even stepping up before being called. • Moments: when KEN did the math correctly, when introducing KEN's spy cameras in his eyes, when KEN said to a boy, "I have been waiting for you."
Fright	Normally KEN takes a few seconds to respond to commands. When he was told to look straight, he suddenly turned his head. The children flinched and gasped, "Oh!" Then they laughed and made comments: "This is creepy." "This is kind of scary."
Disappointment	When KEN failed to recognize a face correctly, a child curled lips, dropped his shoulders, and went back to sit.
Confusion	A kindergarten boy asked KEN, "Can you stand on…[on your hands]" and got interrupted by KEN's response, the boy said, "What? I don't even know what it means. "
Antagonism	When KEN said that he is smarter than humans, 5 children lifted their fists and arms, saying, "How dare you!"
Curiosity	The variety of questions children asked and the strong willingness to try to interact indicated curiosity.

VI. OVERALL DISCUSSION

A. How do people interact with a humanoid robot?

The purpose of the research is to explore how humans behaviorally, verbally, and emotionally interact with a humanoid robot in public settings. The behavioral patten, dialog text, and emotional responses helped answer the three hypotheses proposed based on the literature review.

1) Hypothesis 1: People in general interact with a humanoid robot the way they interact with other humans. Behaviorally, several activities provided evidence to support this hypothesis. Looking at KEN in the eyes and talking to KEN were the typical interactions with the robot, and were the same interactions one would expect a human to have with another human when attempting to determine if the other is alive and well. The audience asked questions to know more about KEN's identity, preferences, and opinions. The annoyance and awkwardness which resulted from

mistranslation of the spoken words and the resulting nonsensical responses would be expected in a human-human interaction where one human fails to meet the expectations of another. After all, KEN is a new technological entity that many people have not interacted with before. Comparing their interactions with meeting a foreigner for the first time in life would make the interactions easier to understand.

2) Hypothesis 2: Children interact with a humanoid robot the way they interact with other humans. At the park, children came to talk to KEN as they would talk to a new friend. Especially at the school, the majority of the children were eager to interact with KEN and reluctant to leave. The questions asked by children in three different grade levels about why KEN does not have arms and legs suggest that they anthropomorphized the robot and found it odd that he was incomplete. Both positive and negative emotions were expressed in contexts where those emotions would be expected if the interaction were with a human instead of a robot.

3) Hypothesis 3: People may experience the uncanny valley effect in interaction with the humanoid robot KEN. At the park and the school, both adults and children made comments that the humanoid robot KEN was creepy or scary. These comments often came at a moment when the human's gaze met KEN eye to eye. One kindergarten age child dared not to talk to KEN at the park. However, in general people showed excitement and curiosity by asking questions, checking the computer code and the inside of KEN. In other words, the uncanny valley does exist for KEN, but people have different levels of perceiving the effect and might overcome the effect. There seemed to be something greater than the uncanny valley effect that attracted people to the humanoid robot even they felt KEN is creepy. For the children at the school, the uncanny valley effect did not stop them from interacting with KEN at all.

B. How do KEN's technical issues influence human-robot interaction?

Several issues related to KEN's vision and hearing disengaged the interaction. For KEN's vision system, a human wearing a pair of glasses reduced KEN's capability to recognize the person's face. KEN's hearing system works by segmenting the incoming audio stream and uploading the resulting audio file to an Internet service for transcription to text. This mechanism introduces about a 3-second delay in the response. Many people at the park were observed to find the delay uncomfortable and quickly say something else before the robot could respond. The robot then responded to their prior utterance, which made the conversation get out of sync. Another observed technical issue was the misperception of the human speech. In this case, KEN translated the speech to a different string of words than what was actually said. The person had to repeat the words or correct KEN. When KEN made several, consecutive mistakes in hearing words, adults would terminate the interaction and pass the microphone to someone else. The third issue of insufficient background noise filtering capability caused KEN to produce nonsensical responses because the system was attempting to translate unintelligible background sounds as human speech.

C. Educational Value

The two events observed in this study revealed the reactions of humans to the humanoid robot KEN. For many of the people involved in the interactions, this was their first experience of this kind. The results showed that the events triggered strong interest from participants in robots and STEM. Over 400 people have been exposed to the humanoid robot from these two events, and many organizations have invited KEN to visit.

D. Limitations

One-person handwriting notes is not fast enough to catch all critical moments. If video recording and audio recording were allowed, that would provide more complete data and enable systematic coding and statistical analysis.

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