Towards understanding causality – a retrospective study of using explanations in interactions between a humanoid robot and autistic children

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***Abstract*— Children with Autism Spectrum Disorder (ASD) often struggle with visual perspective taking (VPT) skills and the understanding that others might have viewpoints and perspectives that are different from their own; i.e., the ability to understand that two or more people looking at the same object from different positions might not see the same thing. The understanding of VPT can be improved by introducing explicit causal explanations in the interactions involving autistic children. Moreover, the use of social robots can help autistic children improve their social skills. We present a retrospective study with Kaspar, a humanoid social robot specifically designed to interact with children with ASD, which aims to define the initial protocol for a study on the effect of causal explanation in VPT provided by Kaspar. To this end, we investigate in which scenarios causal explanations, provided either by researchers or by Kaspar, contribute substantially to the child's understanding of VPT. The results have helped us identify multiple interaction categories that benefit from causal explanation. We have used these results in order to define new interaction games that benefit from causal explanations. These are now progressing through usability assessment experiments.**

I. Introduction

Autism Spectrum Disorder (ASD) is a long-term developmental disorder that affects people's perceptions of the world and how they interact with others. It is characterized by impaired social interaction and interpersonal skills, as well as constrained and repetitive actions [1]. With the possibility of early diagnosis, a range of support may be made available to children with autism in their developmental years.

One of the most recent techniques to support children with ASD is the interaction with social robots. This approach has the goal to mediate between the therapist and children, and to improve the children's social interaction skills. Although the idea of using robots to teach social skills might seem contradictory, the evidence suggests that children with ASD can greatly benefit from the interaction with robots [2]. One of the reasons is that, for children, interacting with a social robot 1) is less challenging than interacting with a person, 2) is more predictable, and 3) is more controllable and adaptable to the child's particular pace and style [3]. In the present research, we will analyze interactions involving Kaspar, which is a state-of-the-art humanoid robot that is primed for interaction with children with ASD [4]. The current patterns of interaction with Kaspar involve a Wizard of Oz (WoZ) approach to progress educational goals.

Children with ASD often struggle with visual perspective taking (VPT), which is the ability to see the world from another person's perspective, making use of both spatial and social information [5,6]. They often find it difficult to understand that others might have viewpoints and perspectives that are different from their own, which is a fundamental aspect of VPT. This skill could be improved by an interlocutor giving explicit causal explanations related to what they see. For the purpose of this research, the main interlocutor is Kaspar, which provides a number of pre-programmed causal explanations through a remote-controlled interface. We aim to investigate this question following a two-step method. At the end of these steps, we will identify a number of scenarios that may demand causal explanation.

As the first step, we present a retrospective study that analyzes previously recorded interactions with autistic children, researchers, and Kaspar, and identify which scenarios are more likely to trigger explanations provided either by Kaspar or the researcher. Its main purpose is to find which scenarios require substantial explanations, so that we can identify behavior patterns that we can implement in future studies.

In the second step, we intend to use the identified scenarios to structurally define a generalized classes of scenarios that demand causal explanation. These classes of scenarios will be concertized into many concrete cases (beyond those observed already in the first step) and are implemented and included in Kaspar explanation repository. The intention of this second part of the project is to utilize the causal explanations from Kaspar and analyze if these explanations improve the children's VPT skills, as well as trust in the technology.

II. Method

This research was approved by the University of Hertfordshire's ethics committee for studies involving human participants, protocol numbers: acCOM SF UH 02069 and aSPECS/SF/UH/ 4654(1). Informed consent was obtained in writing from all parents of the children participating in the study.

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A. Video selection

The videos for the retrospective analysis were selected based on the results of our previous studies [7]. These studies consisted of several different games and scenarios that were developed to assist children with ASD to improve their VPT skills using Kaspar. A large number of interactive games were utilized in these studies involving different actions with the common goal of helping the children to see the world from the robot's perspective, supported by various explanations on the way from both the robot and the experimenter. Each child was required to successfully complete a certain number of trials consecutively to progress to the next game. The selection of videos for this retrospective study was based on the number of trials children needed to progress from one game to the next, assuming that the more difficult a game was – the more trials children needed to progress – the more (complex) explanation they needed as well to complete the game successfully.

B. Video coding

1) Triggers, pre-triggers and explanations

The aim of coding the videos was to find out which actions or scenarios triggered the most explanations provided either by the researcher or the robot. With this purpose in mind, a coding scheme was created with three types of behaviors: the actions that triggered explanations (triggers), the explanations, and the actions that caused a trigger (pre-triggers). In total, there were 21 types of triggers, 17 types of explanations and 8 pre-triggers. Some triggers were, for example, "Researcher (R) asks if Kaspar (K) can see interaction object. Child (C) answers No (incorrect)" or "C shows or hides the interaction object correctly." Some explanations were "R explains the interaction object is not in the right position" or "R explains what K can see or cannot see." Pre-triggers included behaviors such as "R hides or shows an interaction object" or "C is asked to show or hide a toy."

A total of 33 videos were coded using nVivo 12. The videos were coded by a member of the research team and 20% of the videos were second-coded by a different member of the team. There was a strong agreement between the two coders ($\kappa = 0.843$, $p < .001$). Any disagreement was resolved through discussion.

2) Different types of interactions

The interactions with the robot were classified according to the type of tasks or games the children were playing with the robot. These interactions often included a display that showed the child what Kaspar could see through its camera eyes. There were 8 types of interactions:

a) General interaction with Kaspar and Researcher

In this interaction type, the researcher, the robot and the child interacted with each other without following a specific pattern or structure. Usually, they were tickling Kaspar.

b) Showing toys and asking if Kaspar can see the toy

The researcher used 2 different methods to either show or hide the toys from Kaspar without following a pre-specified pattern.

- Method 1: the researcher showed or hid the toys by putting them in front of Kaspar, taking them away, or asking the child to do so.
- Method 2: the researcher moved Kaspar's head to show or hide the toys, or asked the child to do so.

In this scenario, the researcher asked if Kaspar could see the toy. The child usually answered "yes" or "no", which could be correct or incorrect. However, sometimes the child did not respond. After that, the researcher provided an explanation as to what Kaspar could or could not see.

c) Child showing toys by turning Kaspar's head

The researcher asked the child to turn Kaspar's head so the robot could see a specific interaction object in the room. If the child did it incorrectly, usually the researcher provided an explanation that the head was not in the right position. When the child did it correctly, usually Kaspar explained what he can see.

d) Child showing toys in front of Kaspar's eyes

The child was asked to show a specified toy by locating it in the room, and present it to Kaspar by holding it in front of Kaspar's eyes. When this was done correctly, Kaspar explained what he could see. If the child positioned the toy incorrectly, either the robot or the researcher explained that the toy was not in the right position.

e) Turning table

The researcher used a turning table (Figure 1) to show or hide objects from Kaspar and asked the child if Kaspar could see the toy. In this case, if the child gave the correct answer, there was no further explanation but if the child provided an incorrect answer, the researcher provided an explanation about what Kaspar could or could not see. Similarly, sometimes the child was asked to show or hide a toy from Kaspar using the turning table. When they did this correctly, Kaspar explained what he could see. If it was done incorrectly, the researcher provided an explanation about what Kaspar could or could not see.

f) Theory of mind game (hiding the toy when Kaspar sleeps)

In this scenario, there were two boxes (red and blue) and one toy. The researchers and the child put the toy in one of the boxes while Kaspar was awake and looking at them. Then, Kaspar closed his eyes and fell asleep. While Kaspar could not see, the researchers and the child put the toy into the other box and, after that, Kaspar awaked. When Kaspar was fully awake again, the researcher asked the child in which box Kaspar would look for the toy. If the child gave an incorrect answer, Kaspar said that he would have looked in the other box and the researcher explained why. If the answer was correct, Kaspar also provided an explanation, stating that he would have actually looked in that box since this was where he saw the toy before falling asleep.

g) Showing animals on the cube

The child held a cube (Figure 1) that had a picture of an animal on each side and Kaspar asked them to show him a specific animal on the cube. If the child held the cube correctly, with the right orientation, in front of Kaspar's eyes, he explained what he could see. If this was done incorrectly, then the researcher provided an explanation that the object was not in the right position.

Figure 1. Turning table: the the toy is placed on one side of the wall on the table so only Kaspar or the child can see the toy. Cube: there is a picture of an animal on each side. The child is asked to hold the cube so Kaspar can see a specific animal.

h) Opening and closing Kaspar's eyes

In this scenario, there was a toy in front of Kaspar but sometimes he could not see it because his eyes were closed. The researcher asked the child if Kaspar could or could not see the toy. If the answer was correct, Kaspar explained what he could see but, if the answer was incorrect, then the researcher provided an explanation what Kaspar could or could not see.

III. Analysis and results

There was a total of 33 videos with 49 interactions and 18 participants (17 males and 1 female, their mean chronological age was 8.11 years (SD = 1.96, range from 5 to 11 years).

The length of each game or interaction was calculated in minutes and seconds taking the first and the last coded behavior as the beginning and the end of each interaction respectively. This time was then converted into a decimal number for future use. The average duration of each interaction was of 7.08 minutes (7 minutes and 5 seconds), (*SD* = 4.79). The explanations were classified into 3 different categories: researcher's explanations (the researcher explains something about Kaspar), Kaspar's explanations (Kaspar explains something about himself) and Kaspar's tickles or pain (Kaspar says that something tickles or hurts him).

A. Number of explanations in each scenario

A descriptive analysis was carried out, using IBM SPSS 26, taking into account the absolute number of explanations per interaction. Table I shows the total and the average number of explanations in each type of interaction. The results show that the scenario that triggered the most explanations by the researcher is the one in which either the researcher or the child were showing or hiding toys from Kaspar and the researcher asked the child if Kaspar could see the toy (n = 3, M = 10.33, SD = 4.16). Showing toys in front of Kaspar's eyes triggered the most explanations from Kaspar (n = 4, M = 13.00, SD = 1.63). The general interaction included most triggers such as tickles or pain from Kaspar (n = 12, M = 8.08, SD = 7.68).

Because the number of videos for each type of scenarios and the length of each interaction with the robot was not consistent enough to make comparisons, another analysis was carried out using the number of explanations per minute as a measure to contrast each type of interaction. In order to do that, the number of explanations in each interaction was divided by the length in time (decimal number) of such interaction obtaining the value of explanations per minute. There were 4 outliers that only lasted between 14 and 103 seconds. These were too short to contain meaningful interactions. For this reason, they were excluded. Table II shows the total and the average explanations per minute in each type of interaction. The scenario that triggered the most explanations per minute from the researcher was again the one in which either the researcher or the child were showing or hiding toys from Kaspar and the researcher asked the child if Kaspar could see the toy (n = 2, M = 1.49, SD = 0.24). However, in this case, there are only three instances of this type of interaction in which this behavior is presented steadily through a consistent period. The scenario that triggered the most explanations from Kaspar was the one in which the child was asked to show animals on the cube (n = 5, M = 1.92, SD = 0.85). The general interaction included most triggers (n = 9, M = 2.53, SD = 1.08).

Based on both analyses, the scenario that triggered most explanations from the researcher was the one in which the child was asked if Kaspar could or could not see the toy. Nonetheless, there was a pattern of behavior in this particular scenario that it is worth mentioning. When the children were asked the question "Can Kaspar see the animal?", they answered "yes." Later on, one of the researchers realized that the children were answering "yes" to all the yes/no questions. For example, one of the children was asked the question "Do you like broccoli?", to which he answered "yes." Right after this answer, he was asked "Do you hate broccoli?" and he answered "yes" again, indicating that he was answering "yes" to all the yes/no questions. When the same children were given two other options, for example; "Can Kaspar see the tiger or the cat?", the children usually gave the correct answer. We can conclude that the children understood what Kaspar was seeing but the choice of question had to be refined to avoid yes/no answers.

B. Causal relationships

The main purpose of this study was to identify and analyze actions that trigger an explanation, that is, to find those scenarios that are most amenable to a causal explanation and identify the cause-effect relationship in them. A matrix coding query was carried out using nVivo 12 showing the actions that trigger an explanation when they happen within 2 seconds before an explanation. Table III shows the number of times these relationships occur throughout all the interactions. The most common causal relationship is "C shows or hides the interaction object correctly" followed by "Researcher (R) presses button. Kaspar (K) explains what he can see" with 165 instances.

Sometimes, there were actions that occurred right before a trigger (pre-triggers). In order to determine the causal relationships between these two categories, another matrix coding query was carried out showing the pre-triggers that happen within 2 seconds before a trigger. Table IV shows the connection between these two types of behaviors. The most repeated relationship is "Child (C) is asked to show or hide a toy" followed by "C shows or hides the interaction object correctly" with 59 instances.

Taking these two tables into consideration, a chain of events was created by putting together the all the causal relationships (pre-triggers, triggers and explanations). Table V shows the chain of events such as "C is asked to show K a toy by moving K's head, C shows or hides the interaction object correctly, R explains what K can see or cannot see" or "R hides or shows an interaction object, R asks if K can see interaction object. C Yes (incorrect), R explains what K can see or cannot see."

IV. Pilot study design

Taking the results into consideration, we designed a pilot study with 4 interactive games involving causal explanations and VPT. These games were adapted from the scenarios on the videos from previous studies. They were then enriched with causal explanations for different events taking place in the scenario. The pilot study examines whether explanations are understood in line with the interaction scenarios, while children, their parents and their teachers can comment about utility and success of these explanation. The games in the pilot study are the following:

Game 1: Child showing toys in front of Kaspar's eyes

This scenario was kept like in the original game, but causal explanations were introduced when Kaspar could not see the animal. Some of the explanations include "I cannot see it because you are holding it too low."

Game 2: Showing animals on the cube

This scenario was also kept like the original one, but causal explanations were introduced such as: "I can see a picture, but you are holding it the wrong way around, can you turn it so I can see the animal?"

Game 3: Child showing toys by turning Kaspar's head

This game was also kept like in the original game but, again, causal explanations were included: "I cannot see it yet. You didn't move my head to the right position. Please move my head a bit more so I can see it."

Game 4: Turning table

This game was adapted so the child could answer questions about Kaspar's visual perspective while avoiding yes/no questions. In this scenario, one animal is placed on each side of the turntable. The researcher then moves the turntable to different positions and ask the child questions about the visibility of the objects. In addition, Kaspar can request to see a specific animal, and this time, the child would need to move the turntable to the correct position to make it visible to Kaspar.

V. Conclusion

The context of this retrospective study is the analysis of the interaction between autistic children and the humanoid robot Kaspar. In this context, we aimed to find out which types of interactions with the robot and which behaviors are most amenable to a causal explanation. To achieve that, 33 videos from our previous ethically approved studies were re-analyzed classifying different types of interactions and creating causal relations between explanations and their triggers (and sometimes pre-triggers).

The results obtained in this retrospective study have been used to define 4 new interaction games enriched with causal explanations, with the goal of identifying the added value of casual explanation and its impact on trust. These new interactions are validated with the help of children, their parents and their teachers, to assess the most suitable form of explanation that provides better outcomes in a robot-mediated education and therapeutic interaction. The results of our ongoing experiments and impact of causal explanation on trust will be the subject of our future publications.

Also these results will be utilized towards diversifying interaction scenarios and also causal explanation, using formal methods in computer science that can be utilized to generate new scenarios and their associated causal explanations.

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TABLE I. SCENARIOS AND EXPLANATIONS IN ABSOLUTE NUMBERS

	n	**Researcher's explanations per interaction**			**Kaspar's explanations per interaction**			**Kaspar's tickles and pain per interaction**			**Total explanations per interaction**		
Scenario		**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**
General interaction with Kaspar and Researcher	12	63	5.25	8.42	0	0.00	0.00	97	8.08	7.68	160	13.33	12.45
Opening and closing Kaspar's eyes	6	24	4.00	3.00	4	0.67	0.82	17	2.83	3.13	45	7.50	3.67
Showing toys and asking if Kaspar can see the toy	3	31	10.33	4.16	0	0.00	0.00	1	0.33	0.58	32	10.67	3.79
Showing animals on the cube	5	9	1.80	0.05	46	9.20	2.39	4	0.80	1.30	59	11.80	3.70
Showing toys by turning Kaspar's head	5	23	4.60	5.98	20	4.00	2.83	5	1.00	1.41	48	9.60	3.36
Showing toys in front of Kaspar's eyes	4	31	7.75	2.21	52	13.00	1.63	26	6.50	7.55	109	27.25	5.62
Theory of mind game	8	24	3.00	1.52	30	3.75	1.98	2	0.25	0.70	56	7.00	3.02
Turning table	6	20	3.33	4.03	40	6.67	5.28	0	0.00	0.00	60	10.00	5.80

TABLE II. SCENARIOS AND EXPLANATIONS PER MINUTE

	n	**Researcher's explanations per interaction**			**Kaspar's explanations per interaction**			**Kaspar's tickles and pain per interaction**			**Total explanations per interaction**		
Scenario		**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**
General interaction with Kaspar and Researcher	9	1.03	1.28	0.00	0.00	2.53	1.08	3.56	1.23	9	1.03	1.28	0.00
Opening and closing Kaspar's eyes	6	0.51	0.32	0.10	0.15	0.61	1.06	1.22	1.13	6	0.51	0.32	0.10
Showing toys and asking if Kaspar can see the toy	2	1.49	0.24	0.00	0.00	0.12	0.17	1.61	0.41	2	1.49	0.24	0.00
Showing animals on the cube	5	0.26	0.28	1.92	0.85	0.10	0.17	2.28	0.60	5	0.26	0.28	1.92
Showing toys by turning Kaspar's head	5	0.90	1.26	1.15	1.05	0.15	0.23	2.21	0.86	5	0.90	1.26	1.15
Showing toys in front of Kaspar's eyes	4	0.85	0.57	1.30	0.37	0.55	0.64	2.70	0.70	4	0.85	0.57	1.30
Theory of mind game	8	0.30	0.17	0.33	0.12	0.02	0.05	0.64	0.18	8	0.30	0.17	0.33
Turning table	6	0.35	0.26	0.86	0.81	0.00	0.00	1.21	0.63	6	0.35	0.26	0.86

TABLE III. TRIGGERS PRECEDING EXPLANATIONS

Trigger	**Explanation**	**N**
C shows or hides the interaction object correctly	R presses button. K explains what he can see	165
C touches K's feet	K This is nice. It tickles me.	109
C hurts the robot	K Ouch. This hurts.	47
R touches K's feet	K This is nice. It tickles me.	31
C shows or hides the interaction object incorrectly	R explains the interaction object is not in the right position	24
R asks if K can see interaction object. C Yes (incorrect)	R explains what K can see or cannot see	24
C touches K's tummy	K Hahahaha	18
R asks if K can see interaction object. C No (incorrect)	R explains what K can see or cannot see	17
C shows or hides the interaction object correctly	R explains what K can see or cannot see	15
R touches K's tummy	K Hahahaha	14

TABLE IV. PRE-TRIGGERS PRECEING TRIGGERS

Pre-trigger	**Trigger**	**N**
C is asked to show or hide a toy	C shows or hides the interaction object correctly	59
C is asked to show or hide a toy in the turning table	C shows or hides the interaction object correctly	56
R hides or shows an interaction object	R asks if K can see interaction object. C Yes (correct)	51
R hides or shows a toy in the turning table	R asks if K can see interaction object. C Yes (correct)	46
R hides or shows an interaction object	R asks if K can see interaction object. C No (correct)	45
C is asked to show K a toy by moving K's head	C shows or hides the interaction object correctly	43
C is asked to show K an animal on the cube	C shows or hides the interaction object correctly	41
R hides or shows a toy in the turning table	R asks if K can see interaction object. C No (incorrect)	24
R hides or shows an interaction object	R asks if K can see interaction object. C Yes (incorrect)	20

TABLE V. CHAIN OF EVENTS

Pre-triggers	**Triggers**	**Explanations**
C is asked to show K a toy by moving K's head	C shows or hides the interaction object correctly	R explains what K can see or cannot see
C is asked to show K an animal on the cube	C shows or hides the interaction object correctly	R explains what K can see or cannot see
C is asked to show or hide a toy in the turning table	C shows or hides the interaction object correctly	R explains what K can see or cannot see
C is asked to show or hide a toy	C shows or hides the interaction object correctly	R explains what K can see or cannot see
C is asked to show K a toy by moving K's head	C shows or hides the interaction object correctly	R presses button. K explains what he can see
C is asked to show K an animal on the cube	C shows or hides the interaction object correctly	R presses button. K explains what he can see
C is asked to show or hide a toy in the turning table	C shows or hides the interaction object correctly	R presses button. K explains what he can see
C is asked to show or hide a toy	C shows or hides the interaction object correctly	R presses button. K explains what he can see
R hides or shows a toy in the turning table	R asks if K can see interaction object. C No (incorrect)	R explains what K can see or cannot see
R hides or shows an interaction object	R asks if K can see interaction object. C Yes (incorrect)	R explains what K can see or cannot see