Kaspar Explains: The Effect of Causal Explanations on Visual Perspective Taking Skills in Children with Autism Spectrum Disorder*

Marina Sarda Gou[1], Gabriella Lakatos[1], Patrick Holthaus[1], Ben Robins[1], Sílvia Moros[1], Luke Wood[1], Hugo Araujo[2], Christine deGraft-Hanson[3], Mohammad Reza Mousavi[2], and Farshid Amirabdollahian[1]

Abstract— **The present research investigates the effectiveness of introducing explicit causal explanations in a child-robot interaction setting to help children with autism improve their Visual Perspective Taking (VPT) skills. A sample of 10 children participated in three sessions with the robot, during which they completed several VPT tasks. In some of the sessions, the robot provided constructive feedback to the children by giving causal explanations related to VPT; other sessions were control sessions without explanations. The results revealed that children improved their VPT abilities when the robot provided causal explanations. The improvement was greater the first time that the robot provided causal explanations, compared to the later sessions. The findings suggest that using a robot as a tool to teach VPT to children with autism can be effective, especially when the robot provides causal explanations. This study paves the way for further exploring robot's ability to provide causal explanations in other educational scenarios.**

I. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects mainly communication and social interaction skills. It is often characterized by the difficulty in establishing and maintaining relationships with peers, family members, and other individuals [1]. This can lead to isolation, frustration, and behavioral problems. Society does not provide sufficient provisions for such disorders and preparing children for engagement with the society can have beneficial outcomes. Recent advancements in technology have opened up new opportunities for individuals with ASD to improve their social skills. In particular, humanoid social robots have shown promise as tools that can provide a controlled, safe and non-threatening environment where children with ASD can practice and enhance their social interaction and communication skills [2].

Visual Perspective Taking (VPT) skills are an important aspect of social interaction and communication. They relate to the ability to see the world from another person's perspective, taking into account what they see and how they see it [3]. VPT refers to a person's understanding that other people might have a different line of sight to themselves, and to the understanding that two people viewing the same item from different points in space may see different things. Children with ASD often struggle with VPT [4]; this can impact their ability to understand and respond to the perspectives of others. As a result, some social interactions may prove challenging for children with ASD. However, recent research has shown that humanoid social robots can help autistic children improve their VPT skills [5].

These children often experience anxiety and stress in social situations, which can be compounded by negative experiences with peers or other individuals in their community. By using humanoid social robots, children can practice their VPT in a safe and controlled environment, without fear of negative consequences or judgment. Caregivers (e.g., therapists, teachers, and parents) can build on the interest displayed by children with ASD towards the robots and use them as mediator tools, tailoring the interaction to the specific needs of the children at any given time [2, 6, 7].

In addition, social and educational robots can be programmed to provide feedback and support for children with ASD as they work on their VPT. For example, a robot might provide positive reinforcement and encouragement for successful attempts at VPT, or provide constructive feedback for areas that need improvement. This type of support and feedback can help build confidence and motivation in children with ASD, and can provide a foundation for further improvement [8].

Therefore, the use of humanoid social and educational robots should be understood as a mediator tool for researchers and educators; they are to be used for improving VPT skills in children with ASD. By providing opportunities for social interaction and practice, giving feedback and support, and creating a non-threatening and non-judgmental environment, humanoid social robots can play an important role in helping children with autism [9].

The study presented in this paper used the Kaspar robot, a social and educational companion robot developed by researchers at the University of Hertfordshire. It was specifically designed to help children with ASD develop social interaction and communication skills [10]. It is a child-size robot that has been purposefully designed with simplified, realistic human-like features offering a more predictable form of communication, making social interaction simpler, and more comfortable for the child. Kaspar has a child-like appearance and is approximately 56cm tall. The robot is

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1 Robotics Research Group, University of Hertfordshire, College Lane, Hatfield, AL10 9AB, UK. ({m.sarda-gou, g.lakatos, p.holthaus, l.wood, s.moros2, b.robins, f.amirabdollahian2}@herts.ac.uk).

2 Department of Informatics, King's College London ({hugo.araujo, mohammad.mousavi}@kcl.ac.uk) .

3 Garston Manor School: Specialist School for Autism, Learning Difficulties and Speech and Language

equipped with sensors and cameras that allow it to respond to external stimuli, and it is capable of a range of movements, gestures and facial expressions (e.g., eye movements, blinking, nodding, shaking its head, waving its arms, opening its mouth and smiling, portraying ‘happy’ or ‘sad’ expressions, etc.). Kaspar is mainly used as an educational mediator in interaction with other people (peers and adult care givers) and is particularly designed to engage children in activities and games that encourage them to interact with the robot and to develop their social skills (turn-taking, joint attention, cause and effect understanding, etc.). In addition, by using the robot as a tool for research and observation, researchers can gain new insights into the social and communication skills of children with ASD and develop new strategies for helping them to overcome these challenges.

Figure 1. The humanoid social robot Kaspar

This present research aims to investigate the effects of causal explanations provided by the humanoid robot Kaspar in improving the VPT skills of children with ASD in a set of interactive games. These games were designed taking into account the results obtained in a retrospective study [11] analyzing earlier interactions between autistic children and Kaspar, that took place in former studies [9]. These former studies were used to identify scenarios that may be amenable to causal explanations [11] and inform the initial choice of educational games which were later adjusted using co-creation with teachers. This previous research was also used to formalize actual causality and implement it in an interface with Kaspar [12]. This study goes beyond these earlier attempts by designing and running a rigorous experiment, bringing Kaspar furnished with causal explanation to a school, and evaluating its effect on the learning experience of the students with ASD.

In this research, Kaspar will play several interactive VPT games with the children and will provide a number of pre-programmed causal explanations through a remote-controlled interface. The alternative hypothesis of the study is that the causal explanations will have a positive impact on the children’s VPT skills, reducing the mistakes and increasing the correct actions that the children will perform.

The remainder of this paper is organized as follows. In Section II, we provide a detailed account of our methodology, detailing the type of education games used for our study, the type of causal explanations presented to children, and their validation. In Section III, we review the obtained results and analyze them rigorously. In Section IV, we conclude the paper and present the directions of our future research.

II. Method

This research was approved by the University of Hertfordshire’s ethics committee for studies involving human participants, protocol number: SPECS/SF/UH/04944. Informed consent was obtained in writing from all parents of the children participating in the study.

A. Game design

The games were created taking into account the results from a former retrospective study [11]. The objective was to have 4 games related to VPT that elicited causal explanations so the robot had the chance to provide the children feedback to improve their VPT skills.

1) Game 1: Show me the animal

Six laminated pictures of 6 different animals were placed around the room. Kaspar asked the child to show it some specific animal. In the experimental sessions, if the child placed the animal in front of Kaspar’s eyes, they received positive feedback from the robot. If the children made some failed a trial by making a mistake like, for example, placing the picture too low, the robot explicitly explained the reason why it could not see the animal until the children placed the picture in the right position. In the control sessions, children did not receive any feedback. This game had 6 trials.

2) Game 2: Show me the animal on the cube

In this game, the children were holding a cube (Figure 2) that had a picture of a different animal on each side. As in Game 1, Kaspar asked the child to show a specific animal to it. In the experimental sessions, if the child found the requested animal on the cube and turned the cube correctly so to show the requested animal to Kaspar (whilst the child was seeing a different animal on the other side of the cube), they received positive feedback from the robot. If the children failed a trial, the robot explained the reason why it could not see the animal until the children placed the cube in the right position. In the control sessions, children did not receive any feedback. This game had 6 trials.

3) Game 3: Turning Kaspar’s head

The researchers positioned 6 laminated pictures of 6 different animals around the room. Kaspar then asked the child to show it some specific animal. In this game, the child had to move Kaspar’s head so the robot could see the animals. In the experimental sessions, if the child moved Kaspar’s head correctly, they received positive feedback from the robot. If the children failed a trial, like, for example, moving the head too far left or too far right, the robot explicitly explained the reason why it could not see the animal until the children moved the head correctly. In the control sessions, children did not receive any feedback. This game had 6 trials.

4) Game 4: The turning table

This game was divided into two parts and involves the use of the turning table (Figure 2). One animal was placed on each side of the partitions on the table. Kaspar asked the child to show it a specific animal. The child then had to spin the turning table until the right animal was on Kaspar's side of the table so only Kaspar could see that specific animal. This part of the game had 3 trials. In the second part of the game, the researcher was the one spinning the table placing a specific animal in front of Kaspar. Then, the robot asked the child "What animal can I see?" to which the child had to say the specific animal that was in front of Kaspar in the turning table. In both parts of the game, in the experimental sessions, the children received positive feedback every time they performed a successful trial and they received a causal explanation when they failed a trial. In the control sessions, children did not receive any feedback.

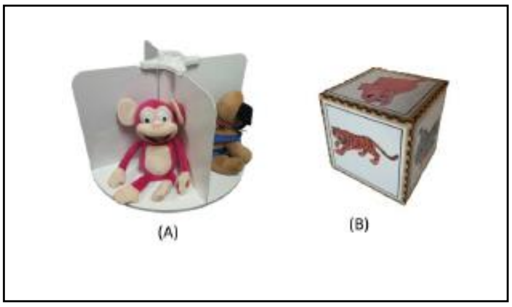

Figure 2. (a) Turning table: the the animal is placed on one side so only Kaspar or the child can see the toy. (b) Cube: there is a picture of an animal on each side. The child is asked to hold the cube so Kaspar can see a specific animal.

B. Conditions

The study was carried out following an ECE – CEC design (E = Experimental, C = Control). The children were divided randomly into two groups and all of them had 3 sessions with the robot. The children who were in the ECE condition had first an experimental session followed by a control session and finally an experimental session again. The children in the CEC group did the opposite. In order to investigate how the causal explanations affected the improvement of the VPT skills, in the experimental sessions, the children received positive feedback every time they succeeded in a trial and a causal explanation when they failed a trial. In the control sessions, they only received positive feedback when they were successful but no casual explanations when they failed in the trials.

C. Causal model

A causal model was developed and implemented to Kaspar [12] so the robot could deliver a causal explanation every time the children failed a trial showing an animal to Kaspar. The causal model is based on Halpern-Pearl's theory of actual causality [14]. It comprises variables that represent the situations in the above-specified games and the observed interactions between the child and the robot. It also comprises equations that capture how different observed phenomena lead to different effects, such as Kaspar's view being obstructed or Kaspar viewing a different anima than intended. The model is instantiated on-the-fly according to what is taking place during a session and is fed into a causal analysis process that explores the model and infers the cause of the particular effect of interest automatically.

A brief overview of the causal model is provided in Figure 3. In this figure, the equations and the variables that model the system are shown. The effect of interest regards to whether Kaspar is physically able to see the animal (which is dictated by whether the view is not obstructed) and whether the animal is correctly shown (which is affected by whether the animal is in his field of view, correct rotation, and distance).

$$\begin{aligned}
&\mathcal{F}_{canKasparSee}() = isKasparAwake = correct \wedge \\
&\quad areKasparsEyesClear = correct \wedge \\
&\quad isKasparsViewClear = correct \\
&\mathcal{F}_{canKasparSeeChosenAnimal}() = canKasparSee \wedge \\
&\quad chosenAnimal = correct \wedge \\
&\quad chosenAnimalPosition = correct \wedge \\
&\quad chosenAnimalRotation = correct \wedge \\
&\quad chosenAnimalHeight = correct \wedge \\
&\quad chosenAnimalDistance = correct
\end{aligned}$$

Figure 3. Causal model: the variables and equations that model the system and represent the behaviour of the interaction between the children and Kaspar.

The main aim is to make children understand the reason why the robot could not see the animal so they could rectify and show it correctly. As an example of the explanations provided by the causal analysis, if the child placed the cube too close to Kaspar's face, then the robot would say "I cannot see the animal because it is too close to my eyes." or "I cannot see the animal because my eyes are covered.". The procedure was designed to follow a Wizard of Oz approach; while the children were playing, the robot's causal explanations and other reactions were triggered by the researchers, who were operating the robot remotely with a keyboard using the implemented causal model.

We provide 16 different causal explanations [12], of which 2 are with respect to the distance between the animal and the robot, 6 are about the position of the animal (e.g., too far to the left), 3 explain that Kaspar's head was not moved correctly, other 3 state that the robot cannot see the animal because the vision is blocked, and 2 of the explanations are related to the child holding the wrong picture or the wrong object. Some of the explanations are specific to the type of game (e.g., moving Kaspar's head) but some could be used in all games.

D. Causal explanations validation

An initial survey was carried out to assess the explanations generated by the system in terms of their validity. For this purpose, we asked 20 adult participants (10 research students or staff members from research groups based at King's College London and the same number from the University of Hertfordshire) to watch videos of Kaspar providing an explanation and then rate each explanation using the Explanation Satisfaction (ES) scale [13]. This survey is based on several key attributes of explanations such as whether they are understandable, satisfying, sufficiently detailed, complete, informative about the interaction, useful, accurate, and trustworthy. These attributes are used to assess the suitability of an explanation provided by an autonomous system. We additionally employed the Negative Attitude towards Robots Scale (NARS) to calibrate the obtained results against potential biases against robots. No other data, i.e., no personal data, was collected and the study was approved by the University of Hertfordshire's ethics committee for studies involving human participants, protocol number: SPECS/SF/UH/04944. In total, we showed 16 videos to participants that contained all possible explanations for the variables of the causal network of the interactive games.

Because participant ratings were not normally distributed, we used the nonparametric one-sample Wilcoxon rank-sum test to test whether ratings on the ES scale were greater than the mean value. Results attest that, when averaging across all the videos, each of the explanations is rated significantly above the neutral value (all $p < 0.001$). Likewise, rating across the explanations are rated above neutral for each of the videos (all $p < 0.001$). Participant ratings on NARS attested a low negative attitude towards robots with mean values for S1 $\approx$ 1.78 (interaction subscale), S2 $\approx$ 2.7 (social subscale), and S3 $\approx$ 1.48 (emotion subscale). S1 and S3 are rated significantly below the neutral value (both $p < 0.001$) whereas S2 could not be reliably distinguished from neutral ($p \approx 0.053$).

These confirms that, with neurotypical adults, the explanations that the system can generate are beneficial to relate cause and effect. Participants consistently rated them as accurate, complete, sufficiently detailed, satisfying, understandable, useful to their goals, and informative about the interaction. Knowing that adults find the generated explanations useful gives us an estimate whether the generated explanations have a potential to help autistic children.

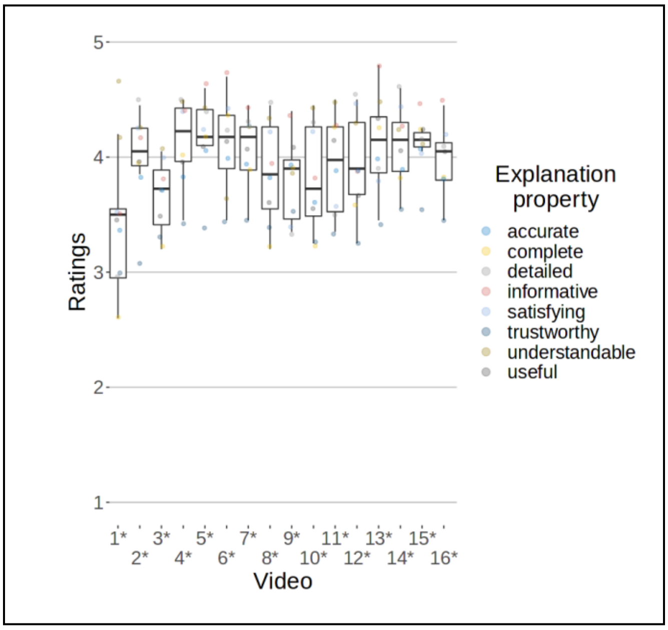

Figure 4. Results of the evaluation of explanations in the multi-centre study. Results of the Explanation Satisfaction scale (5-point Likert scale) grouped by explanation property. Coloured points indicate the mean values of the other dimension. Asterisks mark items significantly greater than the average value.

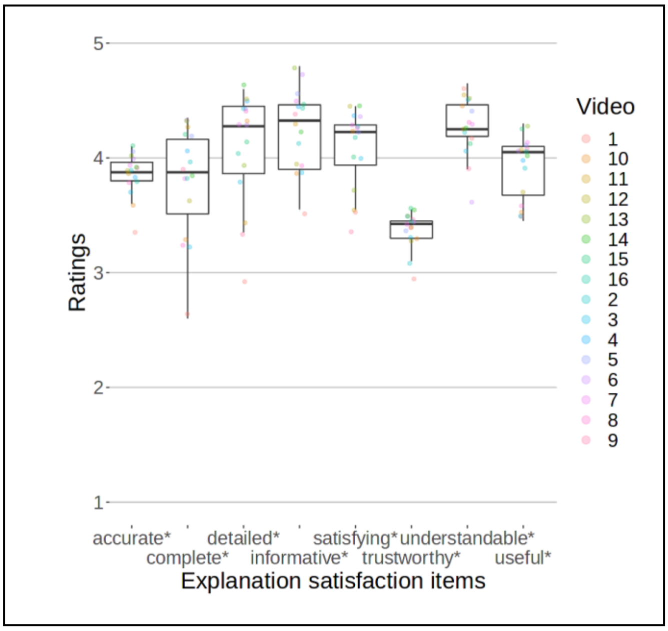

Figure 5. Results of the evaluation of explanations in the multi-centre study. Results of the Explanation Satisfaction scale (5-point Likert scale) grouped by video number. Coloured points indicate the mean values of the other dimension. Asterisks mark items significantly greater than the average value.

III. RESULTS

A. Participants

Ten children with ASD took part in the study in their school. There were 9 males and 1 female and their age ranged from 7 to 10 years old. The participants were divided randomly into the ECE or CEC groups, thus, to filter out interjection effects.

B. Video coding

All the interactions (N = 30) were video-recorded and coded in order to observe differences between control and intervention. The coding scheme included the correct answers after trial, the causal explanations, the incorrect answers (both right after a trial and after an explanation), rectifications (both after an explanation or without explanation) and the total number of trials. We had these parameters for each game and each session of the trial. The videos were coded by a member of the research team and 20% of the videos were re-coded by a different member of the team. There was a strong agreement between the two raters ($\kappa = 0.93$, $p < .001$). Any disagreement was resolved through discussion.

C. The impact of causal explanations

The ratio of correct actions (*RC*) over total number of actions (both correct and incorrect) was taken as a suitable parameter for our analysis. In order to obtain this value, we followed the equation in which, c = total number of correct actions, and i = total number of incorrect actions (c + i equals total number of actions):

$$RC = \frac{c}{c+i}$$

A one-way ANOVA comparing the control and experimental sessions shows a significant difference between the ECE and CEC groups for RC($F(1,28) = 4.461$, $p = .04$, $\eta^2 = .14$). Ratio for incorrect actions over total number of actions was also calculated but given the complete opposite nature of such parameter, statistics obtained are redundant repeating the findings and hence not reported.

An independent sample t-test analyzing only the first session and comparing the two conditions C and E reveals that there was a significant difference between the children who received causal explanations (who had a higher ratio of correct actions) and the children in the control session in their ratio of correct actions ($t(8) = -4.199$, $p = .003$, 95% CI, -0.43 to -0.13, *Cohen's d* = 2.66). Performing the same analysis to compare the two conditions in the second session resulted in ($t(8) = -.027$, $p = .979$) and again in the third session ($t(8) = -1.206$, $p = .262$)), which indicates that after the first session, there were no more significant differences between the two groups. However, we can observe a reduction of the *p* value in session 3, showing that the differences between groups increased after session 2.

The impact of causal explanations can be observed as presented in Figures 6 and 7.

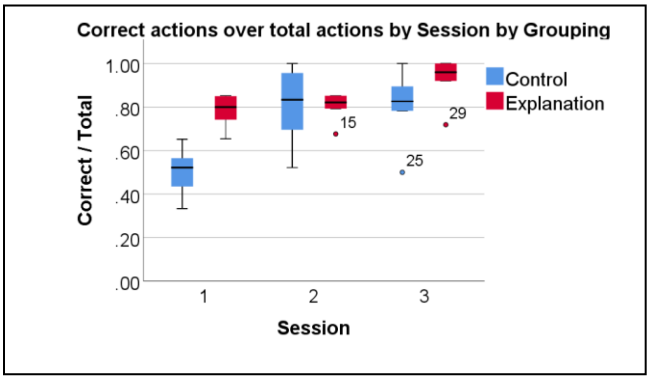

Figure 6. Differences in the ratio of correct actions over total actions, observed for each session of the trial, for both control and intervention sessions. It clearly demonstrates that the causal explanation sessions have resulted in an almost perfect, 100% correct actions.

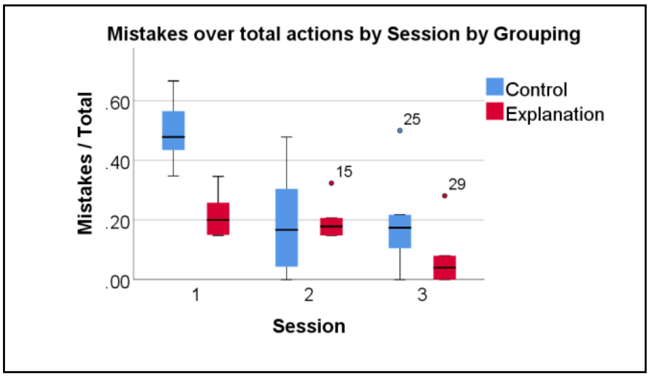

Figure 7. Reducing trend in count of mistakes over total number of actions for each session of the trial and comparing control and explanation sessions.

Table 1 shows the comparison between sessions with explanations and sessions without, it can be also observed that the children were more successful in the sessions with explanations.

TABLE I. CASE SUMMARIES COMPARING SESSIONS

	Control	***Explanation***
#Correct	238	323
#Mistakes	100	71
Total	338	394
Ratio #Correct	0.70	0.82
Ratio #Mistakes	0.30	0.18

IV. DISCUSSION

The results obtained present convincing evidence in favor of the use of causal analysis and explanations in the trial sessions. Modelling the interaction between Kaspar and the children as a causal model and exploring the model to mathematically determine actual causality (according to Halpern-Pearl's theory) made it appropriate to accept the alternative hypothesis. A number of conclusions can be drawn from the presented figures and the summary table.

For CEC: Control (session 1) is followed by an explanation (session 2), which is then followed by a control (session 3). It is interesting to observe that session two has a reduction in mistakes which is then further maintained in session 3. (Blue 0.49, Red 0.20, Blue 0.20).

For ECE: Explanation session is followed by a control session, then followed by another explanation session. It is interesting to observe that when explanations stop, there is immediately more variability, but then session 3 presents a very good reduction of error per trial count (reduction of error count from 29 to 12). This observation is repeated for the ratio of correct actions over total number of actions.

ECE group has better results in count of correct answers and count of number of mistakes, compared to CEC group. This could be explained by the fact that the ECE group had more sessions with explanations than of the CEC group.

Based on the results of this study, it can be concluded that using a social humanoid robot to provide causal explanations can be an effective tool in improving VPT in autistic children. Specifically, the results suggest that this approach was most effective the first time the children interacted with the robot providing causal explanations, which may indicate that the novelty and engagement with the feedback provided by the robot played a key role in the improvement of VPT. That is to say, the results indicate that the explanations had an initial positive effect in the children's VPT. The data shows the biggest difference in session 1, indicating that once the children had been exposed to the explanations, they levelled up their skills and retained them until the last session. These results suggest that causal explanations are a good way to improve the VPT in children with ASD since the children understood the causal explanations given by the robot, applied this feedback to their VPT and preserved this knowledge.

The findings of this study have important implications for the design and implementation of interventions aimed at improving VPT in autistic children. The use of robots in this context may provide a more engaging and interactive experience for children, which could lead to better outcomes. As such, researchers and practitioners may want to consider the use of robots as an adjunct to traditional therapeutic approaches for improving VPT in autistic children.

However, it should be noted that this study has some limitations. First, the sample size was relatively small, which limits the generalizability of the results. Second, the study only investigated the short-term effects of the robot intervention, and it is unclear whether the observed improvements in VPT will persist over time. Therefore, future studies with larger sample sizes and longer follow-up periods are needed to further investigate the efficacy of robot-explained VPT interventions.

In conclusion, the findings of this study suggest that using a robot to provide causal explanations can be an effective tool for improving VPT in autistic children. The results also highlight the potential of HRI as a tool for supporting social communication and interaction in autistic children. Further research is needed to better understand the potential of robot-assisted interventions for improving VPT in autistic children and to explore the optimal conditions for using robots in this context.

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