Can You Guide Me? Supporting Children's Spatial Perspective Taking Through Games with Robots

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Abstract
Perspective taking is essential in composing effective interaction and collaboration; therefore, its importance extends to scenarios where one side of the interaction is a robot or an agent. Furthermore, it is a cognitive skill that develops at an early age and consolidates in elementary school years. In this study, we describe the design and implementation procedure of a gamified platform to evaluate children's perspective taking ability while interacting with a robot. The game is designed with different levels of difficulty with educational implications such as practicing mathematics. We share our insights on the design and the usability of such platforms in children's education, while we detail how they can be beneficial to model the robot's cognitive framework.

Author Keywords
Child-robot interaction; Perspective taking; Mental rotation; Social robots; Education; Game design.

CCS Concepts
•Applied computing → **Collaborative learning; •Social and professional topics** → **K-12 education; •Human-centered computing** → *User studies;* **•Computer systems organization** → *External interfaces for robotics;*

Introduction

We often rely on our cognitive skills to navigate the social world. To thrive within its complex relations and connections, understanding other people's minds and perspectives is of great importance. Depending on the type of interaction, different levels of comprehension are required, as simple as perceiving someone's visual perspective such as what they see, or as complex as comprehending their mental state or belief system. People's actions are directed by their goals, intentions, beliefs, and desires, which may differ from our own. Philosophers and psychologists define the ability to predict the actions of self and others as Theory of Mind (ToM) [2]. To interact, cooperate, or compete with others we need to have a grasp of other's perspectives manifested in a fundamental skill called *perspective taking* [13]. In recent years different literature has pinned different definitions to perspective taking, in which all outline varying degrees of perception or understanding of another person's perspective [12].

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The focus of this study is to explore the benefits of educational scenarios with robots on developing children's spatial perspective taking skills. Developmental psychology research on children's spatial perspective taking has shown how their understanding and reconstruction of another person's spatial perspective develops and consolidates in elementary school years [3]. In general, spatial abilities can prove useful in academic and everyday lives of children. Nevertheless, most school curricula fail to include education on the acquisition of visuospatial abilities [1]. Two main contributing factors for the lack of education on spatial abilities might be first, the spatial ability being a general rather than a domain-specific skill, and second, debates on the age perspective taking abilities emerge in children.

The increasing exposure of children and adults to robots and intelligent agents calls for new interaction paradigms and opens new doors as to how to use the technology in educational contexts.

In this study, we describe the procedure to develop tasks with robots that are educational and require perspective taking. Furthermore, we discuss the possibilities to combine this essential task with other educational topics such as mathematics learning. The main game is inspired by car racing games and remote-controlled cars, while it replaces the car with a robotic entity such as Cozmo or Vector robot.

Related Work

Perspective taking is defined as a sociocognitive process that enables us to be aware and perceive another person's point of view [4]. Taking someone else's perspective can happen in perceptual, cognitive, and affective dimensions. While the *perceptual* dimension focuses on what another person sees or their spatial relationship with the environment [8], the *cognitive* dimension relates to perceiving or estimating what others think or know in certain situations. The *affective* dimension details the ability to estimate what another person feels in certain emotional states [4]. Perceptual perspective taking consists of two sub-dimensions of visual and spatial perspective taking [12, 11]. We integrate the perceptual dimension in the interaction mechanism of the task and expect the cognitive dimension to emerge as a consequence of the interaction. As a result, we give more detail about the perceptual dimension, particularly its spatial sub-dimension that represents the core of our design.

Spatial Perspective Taking

Our current study focuses on level 2 spatial perspective taking. This involves the ability to engage in mental rotation, which provides an opportunity to practice mental rotation tasks in the context of perspective tasks, and in turn leads to children associating agency to our social robot. Surtee et al. [12] describe any perspective taking task to be composed of three basic components: a perspective taker (self), a target perspective (other), and an object or circumstance (object). To develop a perspective taking task, these three components need to be precisely defined.

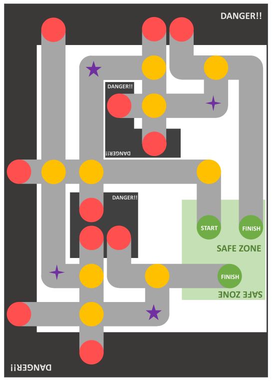

Figure 1: A sample map of the *Basic Guiding Game*. Children are supposed to guide the robot by taking the robot's perspective.

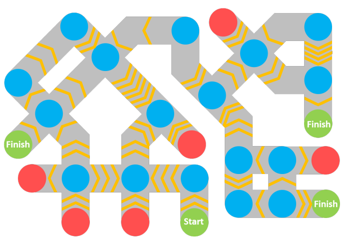

Figure 2: A sample map of the *Arithmetic Guiding Game*. Children only win if they reach the green nodes with certain number of points. They can get positive points if the robot moves in the same direction as the arrows and negative if it moves in opposite direction, also each arrow can be worth 1, 5, 10, 100,... points

The role of Mental Rotation

Research over the decade has shown that as the angular disparity between the perspective taker and the target's viewpoint increases, the speed and accuracy in a spatial perspective task decrease [7]. Consequently, it has been suggested that in spatial perspective taking tasks, people engage in mental rotation of the self rather than object rotation (OR). This means that, in order to take someone else's perspective, humans prefer to mentally rotate themselves rather than rotating the other person or object [7]. It has also been shown that self rotation involves a different cognitive process compared to object rotation [6].

Perspective Taking in Robotics

An emerging body of study in human-robot interaction has discussed perspective taking in robotics, demonstrating that it plays an important role in collaborative and learning scenarios with robots [9, 14]. A more recent research direction tries to look at child-robot interaction scenarios either with autistic or typically developing children. Studies show that robots can be used to teach and develop autistic children's visual perspective-taking skills [15] or building their emotional intelligence skills. Furthermore, some studies try to evaluate how certain affective behaviors of the robot can influence children's cognitive and emotional perspective taking skills.

Child-Robot Interaction and Education

While some studies have focused on the educational aspect of the interaction other studies have tried to evaluate the impact of robots on children's development. In our current study, we are working with the Cozmo robot, which has been used in various studies with children and adults to study human's affective behavior toward robots [5], game development with children [10], and mind perception in human-robot interaction.

Game Design

Think about playing with a remote-controlled car as a child. When you and the car are in the same direction; meaning that the car is moving away from you, controlling seems pretty easy. However, when you and the car are in opposite directions; meaning that the car is moving towards you, things suddenly become more complicated and you are more prone to have an accident. Inspired by remote-controlled cars, we have designed a game with the Cozmo robot, which requires the use of spatial perspective taking for completing the game. The advantages of using an interactive robot in comparison to remote controlled cars are: having a controlled environment to practice perspective taking and the robot providing affective and verbal/non-verbal feedback to the child. Furthermore, we can include various educational goals in our tasks, such as practicing arithmetic topics or reading/writing exercises.

The Map and its Iterations

We designed the map based on three fundaments, the inclusion of the robot as a game character, a perspective-taking application, and an educational goal. Comprehensive School Mathematics Program (CSMP) [1] and other school practices inspired the initial idea of the map, in which the child was supposed to move from a starting point to a designated goal by moving on directional paths from one node to another. The task went through multiple design iterations, with addition of some elements and different educational goals. In this paper, we are going to focus on two of those iterations:

Basic Guiding Game: simply guiding the robot from start to finish while learning to take the robot's perspective (Figure 1).
Arithmetic Guiding Game: basic robot guiding plus doing some arithmetic mind games (addition and subtraction) to reach the game's goal as shown in Figure 2.

[1] http://stern.buffalostate.edu/CSMPProgram/Primary%20Disk/Start.html

Figure 3: Cozmo

Figure 4: Vector

Figure 5: Control Buttons and the screen to present the video feed

The *Basic Guiding Game* includes a core cognitive load: taking someone else's perspective. For this game (Figure 1), we design a simple backstory for the child to guide the robot from start to finish point, while we simultaneously evaluate children's performance in taking the robot's perspective. The game scenario is as follows: Cozmo needs to collect stars in order to survive in a field. To collect the stars the robot needs to take risks and get out of the safe zone (represented by green) and move along the grey roads. If the robot goes to the red nodes within the danger zone (represented by black), it loses the game. We computed the position of the roads and the nodes to serve the perspective-taking goal of the game, which we will describe in detail in the following sections.

Besides the core cognitive load, the *Arithmetic Guiding Game* adds a second cognitive load to the first design: doing basic addition and subtraction. This version also includes a backstory with a different twist. This time the robot should only exit the game after collecting a certain number of points and it loses the game if it reaches the red nodes or the green nodes without collecting enough points . The player collects points by moving on the roads in the direction of the arrows. In this game, each road includes some arrows indicating directions and number of points that the robot can collect. Each arrow counts as one point, so for example, depending on the moving direction moving in a road with 3 arrows can add or deduct 3 points from the total collected points.

The Game Character

The Cozmo or Vector robots (Anki robotics [2] [3]) are used as the main character as shown in Figures 3 and 4. The use of these robots as sidekick character has been researched in recent studies [10]. Our study focus on scenarios with the central goal of practicing perspective taking, developing the robot's cognitive model, and simultaneously understanding how the robots can be used in educational contexts. Using them allows us to incorporate affective models in our interactions and increase the sense of connection to the character in the scenario. As a result, we can equip the robot with affective models to express its emotion during the game and upon winning or losing the game.

The Controller

The controller consist of three or four buttons depending on the use of backward or U-turn motion. The controller used in our first study does not include the backward motion (Figure 5) with buttons representing *front*, *left*, and *right* directions. The controller is placed in front of the child, however, the buttons correspond to the robot's perspective rather than the child's. This information is not shared with children at the start of the game. It is up to them to discover it during the game and change their perspective to match the robot's perspective and choose the correct moving sequence. We just inform children that upon pressing the left or right button, the robot will turn left or right and move to the next node, and we let them explore the rest. We deliberately design the controller to function in this way, so children can experience how to make decisions from the robot's perspective and deal with the consequences of making a wrong move. If the child instructs the robot to move to a direction where there is no road, the robot acts confused and irritated for hitting a blocked road and waits for new instruction.

Optional Features

Depending on the game format, its function, and what we want to achieve we can add or remove some features to the game.

The Video Feed. In the basic guiding game, we are interested in evaluating the effects of having a video feed in the game. As a result, we developed an experimental study using

[2] https://anki.com/en-us/cozmo.html
[3] https://anki.com/en-us/vector.html

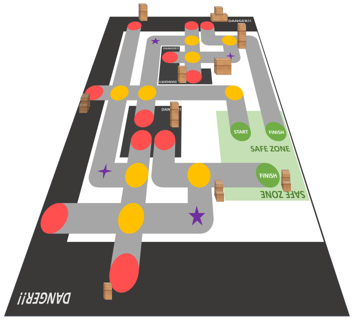

Figure 6: The sample map of *Basic Guiding Game* including the wooden blocks.

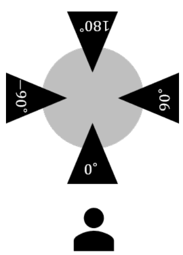

Figure 7: The robot's rotation angle with respect to the player. The tip of the triangles represent the direction of the robot's head.

the video feed as a condition, which tries to recreate the experience of having the first person view during the game. In this case, we were interested to know if adding a first-person point of view helps children in guiding the robot or not. Children could receive the video feed using a tablet in front of them that shows the robot's view in real-time.

Wooden Landmarks. The wooden landmarks can be added to the game either in an assistive manner or as part of the main interaction. For example, in the version of the game with video feed, after initial testing of the system, we realized that the video feed was not informative enough. This was due to Cozmo's camera having limited field of view and its almost monochromatic quality. After encountering the limitations of the robot's camera, we decided to add some landmarks to the game to help children have a better grasp of the robot's perspective during the game (Figure 6). Each landmark is carefully positioned in the robot's line of sight, either inclined to the left or the right in order to assist children in making the correct decision of which side to turn.

The Perspective Taking Task

The core principle of the maps is creating a perspective mismatch between the child and the robot. To reach the goal, children are supposed to align their perspective with the robot's and subsequently learn and practice perspective taking. For example, in the basic map (Figure 6), we have deliberately assigned predefined rotation angles to each node for better comparison between children's performances. Simultaneously, we have tried to give children enough freedom of choice to play while being evaluated. While the basic map only includes $0°$, $90°$, $90°$, and $180°$ rotation angles (Figure 7), the later maps and games are going to explore more angular variations and more complicated roads. Furthermore, with the addition of more educational tasks, we change the focus of the game from perspective taking to topics such as arithmetic and practicing perspective taking on a subliminal level.

Design Implications and Future Work

In this paper, we presented the initial design of an educational platform using robots such as Cozmo or Vector which, does not focus on teaching coding to children. The aim of designing such platforms is two-folded: one is for educating children about perspective taking from spatial and cognitive points of view and two for providing them with a space to practice educational subjects such as arithmetic, reading, or writing in the disguise of a game or interaction with robots. Furthermore, such studies provide us with the data on children's perspective taking and affective behavior while interacting with the robot, which can be used for modeling the robot's cognitive architecture and interaction paradigms. We tested the *Basic Guiding Game* using the researchers in the lab, which brought us valuable insights about some flaws with the video feed, the robot's feedback, and the map. As part of our future work, we are going to test different versions of the platform with children at school. We are particularly interested in evaluating the effectiveness of the interaction in children's learning, which we measure using pretests and post-tests. Furthermore, we will collect and analyze children's perspective taking behavior specifically for design and improvement of the perspective taking model that we are developing for the robot. On a final note, we expect our future studies to inform us of the features that are constructive or destructive to the interaction and the usability of such platforms in children's education, while providing us with the means to test our cognitive model.

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