Studying the Effect of Robot Frustration on Children's Change of Perspective

Conference Paper · September 2019

DOI: 10.1109/ACIIW.2019.8925100

Studying the Effect of Robot Frustration on Children's Change of Perspective

Elmira Yadollahi
GAIPS, INESC-ID, Instituto Superior Técnico (IST), Lisbon, Portugal
CHILI, École Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland
elmira.yadollahi@epfl.ch

Wafa Johal
CHILI, École Polytechnique Fédérale de Lausanne (EPFL),
Lausanne, Switzerland
wafa.johal@epfl.ch

Joao Dias
GAIPS, INESC-ID, Instituto Superior Técnico (IST), Lisbon, Portugal
joao.dias@tecnico.ulisboa.pt

Pierre Dillenbourg
CHILI, École Polytechnique Fédérale de Lausanne (EPFL),
Lausanne, Switzerland
pierre.dillenourg@epfl.ch

Ana Paiva
GAIPS, INESC-ID, Instituto Superior Técnico (IST), Lisbon, Portugal
ana.paiva@tecnico.ulisboa.pt

***Abstract*—The use of robots as peers is more and more studied in human-robot interaction with co-learning interactions being complex and rich involving cognitive, affective, verbal and non-verbal processes. We aim to study the co-learning interaction with robots in the light of perspective-taking; a cognitive dimension that is important for interaction, engagement, and learning of the child. This work-in-progress details one of the studies we are developing in understanding perspective-taking from the Piagetian point of view. The study tried to understand how changes in the robot's cognitive-affective state affect children's behavior, emotional state, and perception of the robot. The experiment details a scenario in which child and the robot take turn to play a game by instructing their counterpart to reach a goal. The interaction consists of a condition in which the robot expresses frustration when the child gives egocentric instructions. We manipulate the robot's emotional responses to the child's instructions as our independent variable. We hypothesize that children will try to change their perspective more when the robot expresses frustration and follow the instructions wrongly, e.g. does not understand their perspective. Moreover, in the frustration groups, we are interested to observe if children reciprocates the robot's behavior by showing frustration to the robot if it is egocentric. Consequently, we expect our analyses to help us to integrate a perspective-taking model in our robotic platform that can adapt its perspective according to educational or social aspect of the interaction.**

***Index Terms*—Perspective-Taking, Cognitive Skills, Child-Robot Interaction, Affective Computing, Cognitive-Affective states, Frustration, Educational Games**

I. Introduction

To create a successful interaction, it is essential for both parties to understand each other [1], [2]. This becomes more relevant when the interaction happens within educational mediums with children involved. [3] In a child-robot interaction scenario, one of the main responsibilities of the robot is to maintain mutual understanding between itself and the child. To maintain such an understanding, it is imperative that both parties have a grasp of each other's perspective. As such, in order to improve the area of human-robot interaction, it is important to study the child's behaviour in the presence of a robot, specially in tasks requiring them to take a different perspective than themselves.

To that end we have designed two studies, one is a *behavioral study* and the other one is a *behavioral-affective study*. This paper focuses on explaining the behavioral-affective study. These studies are supposed to result in a *cognitive behavioral model* that adapts the robot's perspective to a perspective that can either help the child to understand the task better, or help them to develop their perspective-taking skills. Subsequently, for a robot to be able to adapt its perspective based on the child's perspective or requirements of the task, first we need an assessment of the child's perspective-taking abilities. As a result, the behavioral study tries to asses the child's perspective-taking behavior in different situations. The behavioral-affective study explores how a certain cognitive-affective state (e.g. frustration) of the robot can affect the child's effort to change their perspective, especially if this state is in response to the child's perspective-taking choice. These two studies work like two pieces of a puzzle coming together. Our long-term goal is to develop a cognitive behavioral model that adapts the robot's perspective to a perspective that can either help the child to understand the task better, or help them develop their perspective-taking skills.

This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2019 and project PD/BD/135150/2017.

A. Cognitive Dimension: Perspective-Taking

When we discuss perspective-taking, we are talking about the ability to take another person's perspective [4]. The ability to shift one's perspective to others' perspective was considered a major breakthrough in developmental studies in social cognition by Piaget [5]. In Piaget's terminology, this is the ability to decentralize from your own point of view to a different one and to understand things from another perspective [6], [7]. A switch from "egocentric perception" to "allocentric perception" is called decentralization procedure. Taking others perspective can be a cognitive act of trying to understand them (cognitive perspective-taking) or the spatial act of trying to understand their perspective of locations (spatial perspective-taking) [8]. In spatial perspective-taking, we need to understand that people in different locations have distinct physical relationships with objects and each other. This leads to the acquisition of disparate levels of information about the physical world, and at times this can be conflicting. In this case, being able to take other people's perspective can help in reducing the misunderstandings and conflicts. This can be particularly helpful while interacting with children. There are numerous arguments regarding children egocentric behavior in communication [6], [9], [10]. They are said to develop a representational theory of mind by the time they are 4 or 5 and understand that others can have different beliefs from their own [11].

Looking at the previous studies on perspective-taking in human-robot interaction, there is a lot of focus on the way adults perceive robots, their agency, and how perspective-taking can facilitate the execution of some tasks. For example, Lee et al.'s study shows that people make certain assumptions about the robot's knowledge, similar to their human counterparts [12]. The findings of a recent study by Zhao et al. suggests that to trigger people's association of mental states to robots only certain nonverbal behaviours by robots is enough [13]. With these behaviors people tend to take the robot's perspective almost as much as they take other people's perspective. A study by Berlin et al. demonstrates that perspective-taking plays an important role in learning within social contexts by presenting an architecture for collaborative human-robot interaction [14]. The study by Trafton et al. indicates the importance of perspective-taking in human-human interaction, draws conceptual guidelines for human-robot interaction, and demonstrates that perspective-taking plays an important role in collaborative and learning scenarios with robots [15]. On the other hand, there are more recent studies focusing on perspective-taking or emotional understanding that covers perspective-taking with children. The studies by Robins et al. and Wood et al. try to develop child-robot interaction scenarios with Autistic children to develop their visual perspective-taking skills [16], [17]. Leite et al.'s work uses the robot in interactive storytelling activities with the goal to help children building their emotional intelligence skills. The emotional intelligence skills covers the development of cognitive skills and socio-emotional abilities [18].

B. Cognitive-Affective State: Frustration

Frustration can be defined as "the blockage of goal attainment" [19], or "the blocking of a goal-directed behaviour sequence" [20]. In a more general sense, goal blocking or frustration appraisal is used to separate between positive and negative valence. if "an event is goal-congruent, it elicits positive emotions", whereas "if the event is considered goal-incongruent or frustrating, it elicits negative emotions" [21]. Frustration can also be related to goal-importance. In this sense, the more the goal is important for the person, the more likely they become frustrated in a goal-incongruent situation [21]. This model taps into similarities with appraisal model for motivational relevance by Smith and Pope [22]. The link between frustration and goal achievement and importance makes it a relevant cognitive affective state to study in learning environments.

There has been multiple studies with the goal of detecting affect in learning environments which efforts on understanding how affect can impact the student's behaviour and learning [23]. And there are numerous works focusing on reducing the user's frustration [24]–[26]. However, there are two weaknesses of our knowledge in the impact of the affect, particularly frustration, in learning environments. The first one is our poor knowledge of the dynamics between affect and learning environments, either intelligent tutoring systems or robotic platforms. The other one is our lack of clear knowledge on the true negative or positive experiences of the cognitive-affective states such as frustration based on the context of the interaction. For example, Gee proposes that enjoyability of computer games might be enhanced with certain amount of frustration [27]. Baker et al. investigates the occurrence of cognitive-affective states such as frustration during interactions with learning environments, how they persists over time, and to which extent these states correlates with behaviors associated to poorer learning [28]–[30]. Based on Russel's core-affect framework, frustration has a high negative valence and high level of arousal [31]. While, several researchers have hypothesized that frustration is one of the cognitive-affective states that influences cognition and deep learning [32], [33], Perkins and Hill propose that frustration leads to boredom. Although they only show the association between these two states without any evidence proving the causality or temporal relation [34].

In our research, instead of studying children's affective state in response to the interaction with the learning task and the robot, we are going to observe how the robot's frustration when it has problems understanding the child might affect the child's behavior. In essence, the robot becomes frustrated as a result of the child's egocentric instructions. As mentioned earlier, children are more prone to use egocentric perspective in their interactions, and it is hard for them to understand someone else's egocentric perspective as it requires taking someone else's perspective. In short, we are interested to see if the robot's frustration can result in the child's change of perspective, from an easy one (egocentric) to something harder (addressee-centric). This approach is in part similar to studies that induce frustration using games. For example, the work by Scheire et al. tries to induce frustration in users using a game [35]. The game consists of a mouse that fails to correctly respond at random intervals. They collected both physiological and behavioral data from the participants. While they induce the frustration in participants using the game, we try to induce a response in children using a frustrated robot.

C. Emotion Expression in Robots or Agents

Arbib and Fellous propose four reasons for the increasing interest in creating robots with emotional capabilities [36]. They say as the current technology shows us the value of having robots with emotional expressions, the question of robots "having emotions" instead of simulating it comes to mind. Then, they move into exploring how to use neurobiology of emotions to develop "emotional robots" and use them as a test-bed for theories of biological emotions. Marsella et al. in his computational model of emotions expresses the power of emotional behavior of agents in influencing the emotional and motivational states of the user [37]. They mention, if this potential is utilized effectively, it can be used to generate more effective interactions. As an example Lepper shows that student's intrinsic motivation can be impacted by the use of nonverbal displays [38] On the other hand, there are studies that use the emotional behavior of agents or virtual characters to manipulate the student's motivations.

In the following sections, we are going to explore the *Research Questions* that brought this study to life. In the *Experimental Design* section, we explain how we designed the interaction, robot's behavioral model and the study, which is carefully tailored to our research questions and our effort to make a perspective-taking model of the robot. In the *Hypotheses* section, we explain in detail what are our hypotheses and how we have based our design to address each one of them. And finally, in the *Expectations and Conclusions* section, we explain what we expect from running this experiment and how the findings here, fits in the global scope of our work.

II. Research Questions

The interaction between the child and the robot is composed of a game based task. During the interaction each party is supposed to guide the other party to reach a goal by giving them verbal instructions. Since our robot becomes frustrated when the child is egocentric, our research questions deal with how children behave and how the game proceeds in such situations. It is also important for us to observe what are the children' expectations from the robot.

RQ1: *In a scenario that needs perspective-taking, which perspective are children more comfortable to take?*

RQ2: *Do children tend to constantly use egocentric perspective during the interactions or are they willing to change their perspective if it causes dissatisfaction or frustration in their counterpart?*

RQ3: *Do children expect their counterpart to change their perspective when they do so for their counterpart (reciprocate)?*

RQ4: *Do children like the robot that doesn't get frustrated more than the one that does?*

As previously explained, children tend to behave more egocentrically in younger ages. There are also studies showing gender differences in development of socio-emotional skills in early childhood, attributing better emotional development and as a result perspective-taking skills to girls. To further understand our questions in regard to perspective-taking, we introduce frames of reference, which are used to explain the spatial relations in perspective-taking studies. Based on numerous experimental work done in this area, five frames of reference has been proposed [7], [15]. These frames are shown in Table I.

Frame of reference	Origin	Example
Exocentric	World-based	move north
Egocentric	Self-based	move to the right
Addressee-centric	other-based	move to your right
Deictic	Neutral	move here [with pointing]
Object-centric	Object-based	move to the right of the table

TABLE I: Different frames of reference with their examples [15]

III. Experimental Design

A. Interaction Design

For this study, we have created a task that requires the child and the robot to change their perspectives in the physical world. As mentioned, our motive is to discover the features that help the child to understand and perform the task better and improve the interaction quality. Essentially, we want a robot that is capable of changing its perspective according to the task requirement and its counterpart. As a result, we develop a task that gives us the possibility of using different frames of reference. For this study, when the robot is instructing we only use egocentric and addressee-centric perspective models for it. The reason for this selection is the organization of the game, which consists of the child and the robot sitting in the opposite side of each other as shown in Figure 1. In this arrangement the robot's egocentric perspective is different from the child's and understandable if the child takes the robot's perspective e.g. addressee-centric. We will ask children not to use diectic gestures as it would neutralize the conflict that can be created by the use of egocentric perspective. In the interaction design, we also consider the possibility of using ambiguous perspective and prepare the robot to ask for clarification in that case.

This game is designed for two players, each player is sitting in one side of the screen (which is positioned horizontally). In each round one player has the role of the instructor and the other has the role of the manipulator. When it's a player's turn to manipulate the game, only their side of the screen will be activated. On the other hand, when it's a player's turn to instruct they will receive a goal card, similar to the cards

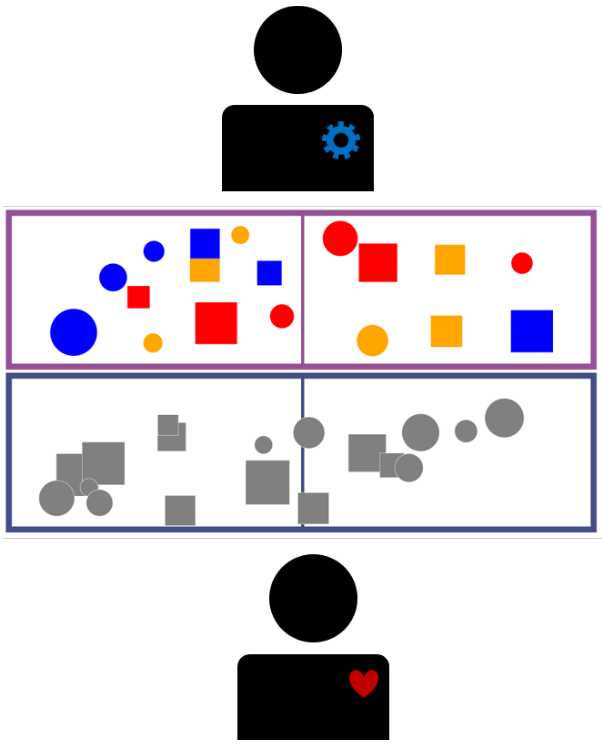
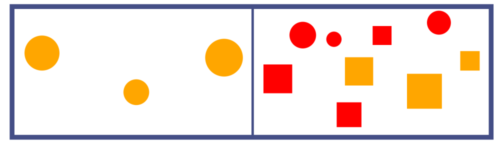
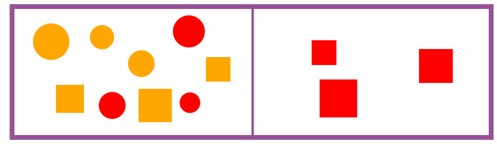


Fig. 1: A schematic of the game with child and the robot sitting arrangement. In this instance, the child is the instructor and the robot is the manipulator, hence the screen on the side of the robot is activated. The game is displayed in its initial stage and the child is supposed to instruct the robot to reach the final state shown in Figure 2b



(a) Example of a goal card shown to the robot



(b) Example of a goal card shown to the child

Fig. 2: Example of the goal cards provided to the robot or the child, which replicates the final status of the game.

shown in Figure 2. The cards will be provided on a stand, only visible to the instructor and not the manipulator. The instructor is supposed to formulate the moves that change the initial state of the game to the goal state.

The instructor is supposed to guide their manipulator in 4 moves to reach either to the goal state or close enough that it's possible to guess the goal. If the players reach the goal correctly, the instructor earns 2 point and the manipulator earns 1 points. If they don't reach or guess the goal, the instructor would lose one point and the manipulator gains or lose nothing. When one round is finished, the players should change their turns and repeat the same procedure in different roles. The players are allowed to ask for clarification before they move the objects, however after moving them they are not allowed to ask anything or change the positions anymore. The current version of the platform is semi-autonomous. This means the robot-instruct part of the game is fully autonomous and the child-instruct part is wizarded. This means when the child is instructing the robot, the experimenter would translates the child's verbal instruction to the robot's language through selecting the components of their sentence from a wizard screen. The reason for this decision is that we are currently avoiding the use of speech recognition with children.

B. Robot's Behavioral Model

We consider expressing frustration as the core behavior of the robot. However, the robot's behavioral model should be designed appropriately for every part of the interaction. Frustration is the response to only one specific behavior from the child. As a result, when the robot is not frustrated the emotional response should be visibly different. We design the robot's emotional response according to different types of the utterances and the instructions that the child gives. First, when the interaction starts and the robot is introduced to the child, it behaves very excited and engaged with the game. When the robot has the role of the instructor, it gives the instructions very clearly, if the child asks the robot to repeats, it repeats the instruction or clarify the sentence. However, the main robot's behavioral changes appears as the robot becomes the manipulator. In this case, the use of different perspectives from the child triggers different behaviors from the robot. If the child instruct the robot with an egocentric perspective, which is easy for the child to formulate and hard for the robot to comprehend, the robot expresses frustration. If the child gives addressee-centric instructions, considering that it would be easy for the robot to comprehend, it shows full understanding of the instruction and proceeds to play the game. And as a possible scenario, if the child gives the robot an incomplete ambiguous instruction, the robot would act confused and ask for clarification.

Considering that the robot used in this experiment is NAO which is only capable of showing certain movement or facial expression, we use a set of programmed animations that fits Nao's movement range. To convey an emotional response of each reaction, we use the robot's eyes to imitate human emotions, considering that the Nao robot cannot render facial expressions. For this purpose, we apply the LED patterns created and evaluated by Johnson et al. [39] allowing to express six basic emotions. This way of emotion expression was previously used in another experiment by the author that studied the effect of robot's deictic gestures on children's performance in a reading scenario with Nao [40].

Groups	Task0	Task1	Task2	Task3	Task4
Frustrated	Introduction/practice	Child-instruct **(Frustrated)**	Robot-instruct	Child-instruct **(Frustrated)**	Robot-instruct
Neutral (Not Frustrated)	Introduction/practice	Child-instruct **(Neutral)**	Robot-instruct	Child-instruct **(Neutral)**	Robot-instruct

TABLE II: Plan of the experiment with a between-subject study design

C. Study Design

This experiment will be carried out in elementary schools. The main target of the experiment are children in the first or second grade in the age range of 6-8 years old. This age range selection is based on the psychological studies on the acquisition of level-1 and level-2 perspective-taking in children [6], [9]–[11]. We divide our participants into two groups and each will go through different conditions.

As mentioned earlier, we are interested to see how children behave when the robot expresses frustration. To have a baseline, we define a control condition without the robot expressing frustration. Considering that, the reason for the robot's frustration is the difficulty of understanding egocentric perspective, we consider the robot to always make a wrong move when the child is egocentric and only expresses different emotion in two different conditions. Here, we are manipulating the emotional responses of the robot as our independent variable. As a result, we have two conditions based on the robot's emotional state. In one condition, the robot expresses its frustration when the child is egocentric, as it is hard to understand someone else's perspective, and then it proceeds to make a wrong move. We call this the *Frustrated Condition*. In the second condition, for addressee-centric instructions, robot's behaviour is similar to the first condition. However, for egocentric instructions the robot's behavior is opposite to the first condition, which means the robot does not express any frustration but it still makes the wrong move This condition is called *Neutral Condition*. In detail, the frustrated behavior is only expressed when the child is using their egocentric perspective to instruct the robot while playing the game. If the child uses an ambiguous perspective, the robot would ask for clarification and if the child uses addressee-centric perspective the robot will proceeds with showing that it understood the instructions clearly and follow them correctly.

As explained, the robot and the child take turn to play the game as instructors. This method of interaction was selected for two reasons: first, it gives us a chance to evaluate the effect of robot's behavior on the child's and second, it engages the children with self-other training [41]. In a study by Okita, it is shown that "self-other training might be an effective way to help students develop metacognitive skills to self-correct and improve performance in elementary mathematics". The whole duration of interaction is divided into tasks with children playing the game while instructing the robot or getting instructions. We call the tasks in which the child is instructing the robot, *child-instruct task* and the one with robot instructing, the *robot-instruct task*. The plan of the experiment based on each condition and task is shown in Table II.

IV. HYPOTHESES

Our base hypothesis is that children will use their egocentric perspective to instruct the robot during the game. We base the robot's behavior on this hypothesis, however, we also define other response models in case children behave differently. As mentioned earlier, we are interested to see if the child changes it's perspective when the robot becomes frustrated. This is considering the fact that changing egocentric perspective to addressee-enteric perspective requires more cognitive work for the child. As a result we hypothesize:

- **H1:** *Children will adjust their perspective to the robot more when the robot is frustrated compared to when the robot is satisfied with the instructions.*

Our second hypothesis is based on the children's perception of the robot.

- **H2:** *Children will like the robot more when the robot does not act frustrated compared to when it does.*

To test this hypothesis and understand children's perception, we will use a modified Godspeed questionnaire for children. After the end of the experiment, the experimenter will ask the questions from the questionnaire and children will answer about their perception of the robot verbally. The questionnaire has been modified to the child's level of understanding, and it consists of 10 questions that the experimenter will ask the children one by one using response metric from never to very often.

We are also interested to observe how children's affective state will be influenced by the robot's affective state. In other words, if they are going to reciprocate the robot's behavior in the frustrated condition, meaning if they act frustrated when the robot is egocentric, especially after they have tried or struggled to change their own egocentric perspective to an addressee-centric perspective because of the robot's frustration. Without making any hypothesis, we are going to analyse their behavior to see if there will be any meaningful differences in children's behavior between the two conditions.

V. EXPECTATIONS AND CONCLUSIONS

In conclusion, the work described in this paper is an on-going investigation, ready for the experimental study to be performed in an elementary school. After running the experiment and analysing the data, if we obcserve that children are willing and capable of changing their perspective with respect to the robot, this gives us a better potential in developing the robot's cognitive model. Especially, since we can expect our cognitive model to be implemented in more cognitively demanding tasks that use perspective-taking. If we observe that children are willing but not capable of changing their perspective, our cognitive model will take that into consideration and the robot will be more adjusting its perspective to children during the interactions. Plus, we can incorporate more scaffolding type behaviors in the robot. Finally if our observations show that children are not willing and capable of changing their perspective, then we can model a behavior that is more toward adapting to the child's perspective during activities. Considering that children might show all or some of these behaviors, we can also have the model that transition between these behaviors based on the child's behavioral response and performance. The result from this study is part of our developmental model and it will be added to the result from the behavioral study and other studies in this line.

ACKNOWLEDGMENT

This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2019 and project PD/BD/135150/2017.

REFERENCES

[1] Herbert H Clark. *Arenas of language use*. University of Chicago Press, 1992.

[2] Herbert H Clark and Catherine R Marshall. Definite reference and mutual knowledge. *Psycholinguistics: critical concepts in psychology*, 414, 2002.

[3] Tony Belpaeme, James Kennedy, Aditi Ramachandran, Brian Scassellati, and Fumihide Tanaka. Social robots for education: A review. *Science Robotics*, 3(21):eaat5954, 2018.

[4] Adam D Galinsky and Gordon B Moskowitz. Perspective-taking: decreasing stereotype expression, stereotype accessibility, and in-group favoritism. *Journal of personality and social psychology*, 78(4):708, 2000.

[5] Jean Piaget and Barbel Inhelder. The child's conception of space. 1967.

[6] Jean Piaget. *The moral judgement of the child*. Simon and Schuster, 1997.

[7] Farilee E Mintz, J Gregory Trafton, Elaine Marsh, and Dennis Perzanowski. Choosing frames of referenece: Perspective-taking in a 2d and 3d navigational task. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 48, pages 1933–1937. SAGE Publications Sage CA: Los Angeles, CA, 2004.

[8] Richard J Boland Jr and Ramkrishnan V Tenkasi. Perspective making and perspective taking in communities of knowing. *Organization science*, 6(4):350–372, 1995.

[9] Nora Newcombe and Janellen Huttenlocher. Children's early ability to solve perspective-taking problems. *Developmental psychology*, 28(4):635, 1992.

[10] Andrew DR Surtees and Ian A Apperly. Egocentrism and automatic perspective taking in children and adults. *Child Development*, 83(2):452–460, 2012.

[11] Aparna S Nadig and Julie C Sedivy. Evidence of perspective-taking constraints in children's on-line reference resolution. *Psychological Science*, 13(4):329–336, 2002.

[12] Sau-lai Lee, Ivy Yee-man Lau, Sara Kiesler, and Chi-Yue Chiu. Human mental models of humanoid robots. In *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*, pages 2767–2772. IEEE, 2005.

[13] Xuan Zhao, Corey Cusimano, and Bertram F Malle. Do people spontaneously take a robot's visual perspective? In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 335–342. IEEE, 2016.

[14] Matt Berlin, Jesse Gray, Andrea Lockerd Thomaz, and Cynthia Breazeal. Perspective taking: An organizing principle for learning in human-robot interaction. In *AAAI*, volume 2, pages 1444–1450, 2006.

[15] J Gregory Trafton, Nicholas L Cassimatis, Magdalena D Bugajska, Derek P Brock, Farilee E Mintz, and Alan C Schultz. Enabling effective human-robot interaction using perspective-taking in robots. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 35(4):460–470, 2005.

[16] Ben Robins, Kerstin Dautenhahn, Luke Wood, and Abolfazl Zaraki. Developing interaction scenarios with a humanoid robot to encourage visual perspective taking skills in children with autism–preliminary proof of concept tests. In *International Conference on Social Robotics*, pages 147–155. Springer, 2017.

[17] Luke Wood, Kerstin Dautenhahn, Ben Robins, and Abolfazl Zaraki. Developing child-robot interaction scenarios with a humanoid robot to assist children with autism in developing visual perspective taking skills. In *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pages 1055–1060. IEEE, 2017.

[18] Iolanda Leite, Marissa McCoy, Monika Lohani, Daniel Ullman, Nicole Salomons, Charlene Stokes, Susan Rivers, and Brian Scassellati. narratives with robots: The impact of interaction context and individual differences on story recall and emotional understanding. *Frontiers in Robotics and AI*, 4:29, 2017.

[19] Craig A Anderson and Brad J Bushman. Human aggression. *Annual review of psychology*, 53, 2002.

[20] Klaus R Scherer. Appraisal considered as a process of multilevel sequential checking. *Appraisal processes in emotion: Theory, methods, research*, 92(120):57, 2001.

[21] Peter Kuppens and Iven Van Mechelen. Interactional appraisal models for the anger appraisals of threatened self-esteem, other-blame, and frustration. *Cognition and Emotion*, 21(1):56–77, 2007.

[22] Craig A Smith and Lois K Pope. Appraisal and emotion: The interactional contributions of dispositional and situational factors. 1992.

[23] Arthur C Graesser, Sidney D'Mello, and Natalie Person. 19 meta-knowledge in tutoring. *Handbook of metacognition in education*, page 361, 2009.

[24] Kate Hone. Empathic agents to reduce user frustration: The effects of varying agent characteristics. *Interacting with computers*, 18(2):227–245, 2006.

[25] Jonathan Klein, Youngme Moon, and Rosalind W Picard. This computer responds to user frustration: Theory, design, and results. *Interacting with computers*, 14(2):119–140, 2002.

[26] Scott W Mcquiggan, Sunyoung Lee, and James C Lester. Early prediction of student frustration. In *International Conference on Affective Computing and Intelligent Interaction*, pages 698–709. Springer, 2007.

[27] James Paul Gee. *Situated language and learning: A critique of traditional schooling*. routledge, 2012.

[28] Ryan SJd Baker, Sidney K D'Mello, Ma Mercedes T Rodrigo, and Arthur C Graesser. Better to be frustrated than bored: The incidence, persistence, and impact of learners' cognitive–affective states during interactions with three different computer-based learning environments. *International Journal of Human-Computer Studies*, 68(4):223–241, 2010.

[29] Ryan SJD Baker, AMJA De Carvalho, Jay Raspat, Vincent Aleven, Albert T Corbett, and Kenneth R Koedinger. Educational software features that encourage and discourage "gaming the system". In *Proceedings of the 14th international conference on artificial intelligence in education*, pages 475–482, 2009.

[30] Ryan Baker, Jason Walonoski, Neil Heffernan, Ido Roll, Albert Corbett, and Kenneth Koedinger. Why students engage in "gaming the system" behavior in interactive learning environments. *Journal of Interactive Learning Research*, 19(2):185–224, 2008.

[31] James A Russell. Core affect and the psychological construction of emotion. *Psychological review*, 110(1):145, 2003.

[32] Barry Kort, Rob Reilly, and Rosalind W Picard. An affective model of interplay between emotions and learning: Reengineering educational pedagogy-building a learning companion. In *Proceedings IEEE International Conference on Advanced Learning Technologies*, pages 43–46. IEEE, 2001.

[33] Brian C Patrick, Ellen A Skinner, and James P Connell. What motivates children's behavior and emotion? joint effects of perceived control and autonomy in the academic domain. *Journal of Personality and social Psychology*, 65(4):781, 1993.

[34] Rachel E Perkins and AB Hill. Cognitive and affective aspects of boredom. *British Journal of Psychology*, 76(2):221–234, 1985.

[35] Jocelyn Scheirer, Raul Fernandez, Jonathan Klein, and Rosalind W Picard. Frustrating the user on purpose: a step toward building an affective computer. *Interacting with computers*, 14(2):93–118, 2002.
[36] Michael A Arbib and Jean-Marc Fellous. Emotions: from brain to robot. *Trends in cognitive sciences*, 8(12):554–561, 2004.
[37] Stacy Marsella, Jonathan Gratch, Paolo Petta, et al. Computational models of emotion. *A Blueprint for Affective Computing-A sourcebook and manual*, 11(1):21–46, 2010.
[38] Mark R Lepper. Motivational considerations in the study of instruction. *Cognition and instruction*, 5(4):289–309, 1988.
[39] David O Johnson, Raymond H Cuijpers, and David van der Pol. Imitating human emotions with artificial facial expressions. *International Journal of Social Robotics*, 5(4):503–513, 2013.
[40] Elmira Yadollahi, Wafa Johal, Ana Paiva, and Pierre Dillenbourg. When deictic gestures in a robot can harm child-robot collaboration. In *Proceedings of the 17th ACM Conference on Interaction Design and Children*, number CONF, pages 195–206. ACM, 2018.
[41] Sandra Y Okita. Learning from the folly of others: Learning to self-correct by monitoring the reasoning of virtual characters in a computer-supported mathematics learning environment. *Computers & Education*, 71:257–278, 2014.