Robo Ludens: A Game Design Taxonomy for Multiplayer Games Using Socially Interactive Robots

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The use of games as vehicles to study human-robot interaction (HRI) has been established as a suitable solution to create more realistic and naturalistic opportunities to investigate human behavior. In particular, multiplayer games that involve at least two human players and one or more robots have raised the attention of the research community. This article proposes a scoping review to qualitatively examine the literature on the use of multiplayer games in HRI scenarios employing embodied robots aiming to find experimental patterns and common game design elements. We find that researchers have been using multiplayer games in a wide variety of applications in HRI, including training, entertainment and education, allowing robots to take different roles. Moreover, robots have included different capabilities and sensing technologies, and elements such as external screens or motion controllers were used to foster gameplay. Based on our findings, we propose a design taxonomy called Robo Ludens, which identifies HRI elements and game design fundamentals and classifies important components used in multiplayer HRI scenarios. The Robo Ludens taxonomy covers considerations from a robot-oriented perspective as well as game design aspects to provide a comprehensive list of elements that can foster gameplay and bring enjoyable experiences in HRI scenarios.

CCS Concepts: • **Human-centered computing** → *Human computer interaction (HCI)*; *Collaborative interaction*; • **Computer systems organization** → *Robotic autonomy*;

Additional Key Words and Phrases: Game design, social robotics, social interaction, education, embodiment, multiplayer, cognitive stimulation, therapy

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1 INTRODUCTION

The study of games, user experience, gaming, and play has been established as a promising domain of research within the field of **human-computer interaction (HCI)** in past decades. From the

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Homo Ludens manifesto described by Huizinga to the contemporary video gaming culture, play has been defined as a primary necessity of the human beings, clearly influenced by socio-cultural elements [28]. A more extensive definition of play describes it as an activity that is (i) free: there is no obligation to do it; (ii) separate: well-defined and circumscribed within limits of space and time; (iii) uncertain: the course cannot be predicted or determined; (iv) unproductive: does not create any goods or wealth; (v) governed by rules: conventions and laws that regulate it; and (vi) make-believe: rooted in imagination [10]. De-trivializing the idea of play by making this activity a fundamental part of human history was one of the most important contributions of some of the most influential humanists theorists of play [14].

A game is a system in which players engage in imagined and artificial conflicts and situations, defined by rules and objectives, producing a quantifiable outcome [65]. Games have been used as a medium to study human behavior in several emergent research fields such as artificial intelligence and **human-robot interaction (HRI)**. Although the situation where coexistence between humans and intelligent robots has been described as futuristic and sometimes dystopic, there is growing evidence that suggests that we are already surrounded by a diverse amalgam of simple robots such as computerized household appliances and cars [54]. With the rapid pace of technology development, socially interactive robots have been investigated to be integrated into activities of daily living, providing scenarios for human-robot teamwork and collaboration [9]. Many of the HRI design research questions can be answered only throughout extensive, repetitive, controlled, and carefully prepared experiments. Correspondingly, games have been proposed as a more enjoyable, less monotonous, and more interactive way to study human behavior in the presence of embodied robotic systems, since gameplay can produce a more naturalistic environment to explore how human players react to robots' actions [95].

Depending on whether the games have a specific application or purpose beyond entertainment, the terms serious or applied games have been used repeatedly to distinguish between games with particular purposes such as training, healthcare promotion, or education, and games that are merely made for entertainment [49]. In this regard, games and serious games have been used by HRI researchers to engage different audiences with gameplay aiming to provide enjoyable scenarios to study aspects such as human perception [96], collaboration [76], competence [9], and trust [94], among others. Although some of the HRI studies that have implemented, adapted, or integrated games or game elements to investigate players' behaviors have shown promising results in successfully achieving the level of natural human interaction and game user experience, still, it is often unclear how specific game elements were used in alignment with the robots' capabilities to elicit human behaviors and reactions [95, 96]. Instead, we argue that game elements should be well understood to deconstruct the specific components needed to allow robots a meaningful mediation in the interaction with human players. One of the most used approaches to defining fundamental elements in games is the elemental tetrad [67]. The tetrad defines four elements that should be well-balanced when designing games: (i) mechanics, (ii) story, (iii) aesthetics, and (iv) technology. Game mechanics are the core of the game: the interactions and relationships between players, defined by aspects such as space (where is the game happening), time (when: discrete, continuous), objects, attributes and states (what can be done with game objects), actions (verbs of game mechanics), and rules. To be balanced, game mechanics often use rewards and punishments that allow players to understand whether what they are doing is "good" or "bad" in terms of gameplay. The game story encompasses the narrative that often guides players while interacting with the game. Game aesthetics deals with the visual, artwork, and any other element that enriches the experience through the stimulation of senses (e.g., audio, smell, haptics). Finally, game technology refers to the medium of the game experience, the physical objects that make it possible. It appears that

essential game design elements are often neglected when designing experiments in HRI scenarios that aim to study human behavior and reactions of humans to social and interactive robots.

Recently, the study of multiplayer HRI scenarios, where more than one human player interacts with one or more embodied robots, has raised the attention of the research community, since playing games is an inherently and noteworthy form of social functioning [28]. Multiplayer games are fundamentally different from single-player games, and they naturally encompass more complex dynamics and situations due to the unpredictability of human-human behavior. From a game design perspective, one can say that creating a multiplayer game will take more time and effort when compared to a similar single-player game [67]. Moreover, the same game played in single versus multiplayer (e.g., competitive, collaborative) modes can create very different experiences for users, shaping the gameplay towards producing more engaging and sometimes more challenging game experiences in multiplayer situations [74].

Despite the efforts of investigating methods for the creation and evaluation of games in HRI scenarios [95], reviews that analyze multiplayer HRI scenarios and identify fundamental game elements used in HRI studies are scarce. Such information is important, because it facilitates a comprehensive comparison of individual game elements that have been considered by researchers while creating multiplayer experiences with robots. More significantly, it allows identification of important categories that must be considered when designing games mediated by socially interactive robots in multiplayer scenarios. Thus, in this article, we put forward a scoping review of games used in multiplayer scenarios where embodied robots and human players interact together towards accomplishing specific game objectives. This scoping review establishes an opportunity to:

- (i) Analyze HRI scenarios when two or more human players are encouraged to interact with one or more robots with capabilities to mediate social interactions.
- (ii) Investigate how specific game design elements (e.g., mechanics, technology) are used in HRI scenarios that promote multiplayer social interactions and identify unforeseen limitations and successes to provide an informed and comprehensive diagnosis of the field.

In addition, based on this review, we identified HRI elements and game design fundamentals to propose a novel taxonomy that helps to classify and categorize important components used in multiplayer HRI scenarios covering considerations from a robot-oriented perspective (e.g., role, appearance, motor abilities) as well as game design elements (e.g., mechanics, feedback, technology, application field). Other HRI taxonomies have been proposed to (i) better define human-robot interrelations [97], (ii) identify opportunities for robot-assisted training systems [84], (iii) categorize action representations in robotics [99], (iv) promote the inclusion of ethical guidelines in HRI research [75], and (v) improve interface design and user experience in teleoperation applications in games [60]. The new taxonomy proposed in this article unveils not only the fundamental elements to consider when designing games (in particular multiplayer games) in HRI scenarios, but also provides a comprehensive description and illustrative definitions of each category, which contributes to the body of knowledge of the convergence between HRI and game user research. Multiplayer games have been chosen, since they have been less explored in HRI studies. Research has shown that players react differently when playing with other human players as compared to artificial agents [74], and the overall multiplayer gaming experience produced higher pleasure and perceived arousal [91], as well as more fun and less boring experiences in players [47].

By creating this taxonomy, we hope to contribute to the future design of HRI scenarios where robots can enhance social experiences among different end-users by a meaningful and comprehensive use of games. The final taxonomy might be used for both game designers and researchers in social robotics and HRI to create multiplayer games empowered with specific game elements that have been shown to be effective for specific purposes. The taxonomy also serves as a mediator

between researchers in the fields of HCI and game design and those familiar with social robotics and HRI, facilitating the identification of common concepts for the use of games in social robotics. Finally, we hope that this endeavor will also facilitate fruitful collaboration and exchange of ideas from those two communities.

2 METHODS

A scoping review was conducted to investigate how socially interactive robots have been used to conduct HRI experiments involving at least two human players and one embodied robot. Electronic search strategies were used to obtain scientific papers. The review was carried out because preliminary research did not uncover a comprehensive summary of game design elements, characteristics, and implementation strategies to fully understand the impact of game design choices in multiplayer games using socially interactive robots. The research question was, “Which are the categories that better represent the fundamental elements that should be considered when designing multiplayer games for HRI scenarios?” Ethical approval was not required to carry out the scoping review.

2.1 Search Strategy

Publications were identified through searching electronic databases of ACM Digital Library, IEEE Explorer (Xplore), PubMed, and SpringerLink. The search was limited to journal, conference proceedings, and extended abstracts published in English. The search was carried out in September of 2019, including papers published from 2010 and ahead, since we wanted to capture multiplayer HRI scenarios using contemporary robots and sensing technology. We were particularly interested in the conference proceedings from specialized social robotics conferences such as the *International Conference on Social Robotics* and the *International Conference on Robot & Human Interactive Communication* as well as specialized journals such as the *International Journal of Social Robotics* (Springer) and *ACM Transactions on Human Robot Interaction*. Additionally, a free, grey literature search was carried out in Google Scholar, particularly after choosing one specific paper, we also checked its citations looking at contributions in similar directions. The terms included in the search were: “robot,” “social,” “game,” “interaction,” “multiplayer,” “human-robot interaction,” “interactive,” “assistive,” “socially interactive.”

2.2 Eligibility & Screening

Publications were included if:

- (i) They used games (as previously defined [65]) instead of simulated tasks.
- (ii) They included embodied robots as opposed to virtual agents.
- (iii) They proposed multiplayer gameplay: three or more players, including at least two human players and one embodied robot.
- (iv) They covered experimental research or game design concepts.

Since the fields of HRI and socially interactive robots is still in its early stages, many of the included studies are small (e.g., in terms of sample size), exploratory, and do not provide an in-depth description and understanding of HRI principles and game design elements used. Nonetheless, they provide valuable insights into the motivators to study multiplayer games using HRI scenarios and the most popular robots used in the field (and why they have been used) as well as the game elements included. Publications were not excluded considering the quality of the methodological procedures or the level of sophistication of the robot due to the emergent nature of the field. Finally, after duplicate references were removed, titles, abstracts, and keywords were screened using the above-mentioned eligibility criteria.

Fig. 1. Schematic flow diagram of the review process.

2.3 Data Extraction

Variables extracted were study context, type of robot, interaction modality, specific game features described (e.g., description and goal, mechanics and feedback, and technology) number of players and main findings. Unlike a systematic review, scoping reviews aim to present a narrative account and, therefore, the results are described in sections aligning the research objectives [50].

3 RESULTS

3.1 Analysis and Synthesis

The initial search produced 3,050 results in four databases. After filtering and removing duplicates, 1,622 references remained. Non-relevant research was identified by removing papers that were not HRI research (e.g., multiplayer videogames), or they presented only vague concepts or study designs that did not provide enough information for us to analyze them. Titles and abstracts were screened according to the full eligibility criteria resulting in 39 references for which full articles were obtained. After screening the full texts, only 16 papers were selected, since they fully met the eligibility criteria. Of the 16 selected articles, two papers were related to setups/games already described in other included publications; thus, the information was used to complement the description. Also, of the 16 articles, 7 were journal publications and 9 were conference papers. Therefore, a total of 16 articles were finally included to be analyzed (see Figure 1 and Table 1).

3.2 Analysis and Synthesis

Five sections were created to analyze the selected articles described as follows:

Table 1. Summary of the Included Publications Describing the Robot Type, Research Context, Game Features, Number of Players, Main Findings, and References

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
Kaspar ^a Autonomous Active player	Training Support collaborative play among children with autism. The study objective specifically explored a long-term use of the robot to foster collaborative gameplay and encourage supportive skills among children with autism.	Imitative collaborative game. Turn-based gameplay, one player directing, two players imitating. Players would get their turn to direct the others and the round ends when all the shapes had been selected.	Players alternate between choosing a specific pose and copying or imitating the pose from the directing player. When players posed in the same way for long enough, a shape will spin around on the screen and victorious music would play. Kaspar has programmed behaviors to react during the gameplay: <ul style="list-style-type: none"> • Greet children at the beginning and said goodbye • Said something when children are not acting as expected. • Indicate and reinforce decisions. 	Kaspar is capable to express emotions by using gestures, facial expressions, and speech. Wiimote controllers were attached for gesture detection. A horizontally oriented screen is used to aid the interaction. A minimalistic approach to the game's visual design for simplicity.	Three: two human players and one robot player	Children successfully engaged with the robot and each other during the games Improvements in social behaviors	[88]
Corkscrew robot figurine ^a Autonomous Referee	Entertainment Explore deception in multiplayer games.	Turntable-like setup. Multiplayer, reaction-time game where participants compete against each other. The main goal is to detect the vibration of a specific "target" as quickly as possible. The round ends when a player has been identified as the winner or when everybody loses.	The robot carries fruits on top and makes them vibrate. One fruit is the target. Players placed around the table, use bottle-like controllers with push buttons to react once the vibration of the target fruit is detected. The robot detects the first player to push the button and declares him/her as the winner. The first player to react to the vibration of the target is the winner and gets to eat one grape. The rest of the players eat carrots.	The corkscrew robot has vibration, screen-based visual feedback and an expressive corkscrew (quasi-anthropomorphic) The robot also included connectivity with screen to support human-robot communication.	Five: Four human players and one robotic referee	The robot was able to deceive participants and game balancing strategies were not detected by players. Participants were more prone to accept lies in this robot than robots in general.	[87]
Nao (Torso Robot) ^b Semi autonomous Tutor	Training and Education Empathic robotic tutor for children in primary schools. The robot is used as a mediator between expectation and satisfaction.	City-planning online game (Enercities). Players learn how to design sustainable cities by understanding energy-related implications. The robot was interfaced with a videogame and acts as a tutor, cooperating to help in achieving and completing the tasks.	Nao is capable of: <ul style="list-style-type: none"> • Informing the game playing and pedagogical decision-making • Automatically adjust tutor strategy to follow "action tendency." An external Wizard is used to control the flow of interaction along with the flow of the game. The system interacts back through the robotic tutor performing social, expressive and gameplay-related behavior.	Nao was empowered with an Interactive touch table, video cameras, lavalier mics and a Woz interface. Perceptive: head position and gaze tracking, facial expression recognition (using the Kinect sensor)	Three: two human players and one robotic tutor	Current capabilities of the robotic tutor are at an appropriate level of development to sustain a collaborative educational interaction. Players manifested the robotic tutor to be a good game companion and revealed high levels towards the tutor's appropriate competence.	[4], [33]

(Continued)

Table 1. Continued

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
Nao ^a (renamed Nima) WoZ Interaction Trainer (Psychologist Assistant)	Healthcare and Assistance A robotic assistant to a psychologist for children with cancer helping them to deal with their pain and distress. The study aimed to explore the friendship bond between the robot and the children.	Instructive game for guessing previous situations. The robot plays a short dialog from a previous therapeutic session and the children have to guess when the session occurred.	The robot plays different roles (doctor, nurse, chemo-hero, cook), involving children in stories. Nima as a Doctor Through internet connection, Nima can learn and answer questions about medical devices, treatment procedures, possible surgeries, etc. Nima as a nurse Nima teaches children relaxation methods to decrease their pain and stress through imitation and discussion.	Nao has programmed conversations (microphones and speakers) and body postures Onboard cameras are used to take photos during each session.	Four (or more): one human psychologist, one robotic assistant, two or more children.	Children's stress, depression, and anger were considerably alleviated after social robot-assisted therapy.	[2]
AIBO Robot ^b (Pet dog-like) Autonomous Social mediator	Entertainment Remote human-human interaction with a collaborative game. A pet-like robot is used as a mediator to support communication and investigate preferences once compared to systems that do not involve robots Teleoperation	A collaborative 2D maze game where players have to guide a virtual dog-like character around various levels, collecting as many hidden bones as possible by interacting with the robotic dog	The guidance of the virtual character is done by real-time tracking of a pink-ball. The physical robot provides feedback when the virtual robot is close to a hidden bone in the maze, thus helping them to succeed in the game. Sniffing behaviors were programmed to reward players when they were close to a hidden bone. AIBO physically points to the target to help players.	The AIBO robot has technology for object recognition and head movement. It was empowered with a mood-related behavior and physical robot is connected with a virtual representation to play the game.	Three: two human players and one robotic mediator	Participants expressed more social cues when using the robot as a mediator. Familiarisation with the robot and task performance are presented as concerns in this study.	[56]
E-puck Robot ^b Controlled Executor	Training Movements emulated on robots with sensory-motor features as part of games to improve social interaction among children with autism	Emotion recognition game based on stories and movements. A big round disc with directional arrows accommodates several children. Arrows are associated with the emotions described in the game storyline. When the emotion is identified, players have to collaborate by choosing positions in the round disc that matches the identified emotion, therefore commanding the robot.	LED arrows are used to represent colors, resembling the emotion using the traffic light metaphor. Children, standing on top of the platform, had to negotiate their positions. Once in the right position (disc tilted), the robot triggers the behavior.	The E-puck Robot has wireless communication and two wheels for navigation. Lights were used to represent emotions	Four: three human players and one robot player.	An example game platform was presented. Results show that quantitative movement parameters can be matched to the emotional state of the embodiment agent (human or robot)	[6]

(Continued)

Table 1. Continued

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
<p>Furhat Human-like Robot^a</p> <p>Woz Interaction</p> <p>Active player</p>	<p>Entertainment</p> <p>Three party conversations with two humans and one robot. Collaborative human-robot problem-solving scenario when objects relating to the task that is discussed are present, and the symmetry of the robotic head pose as well as behavioral patterns from human players were studied</p>	<p>Adaptation of the “Desert Survival” team building game. Players are asked to collaboratively prioritize a set of items based on their usefulness for survival in a desert after an imagined plane crash. Players have to rank-ordered 5 items for their survival value, engaging with their social partners and discussing to get a final ranking. The game ends after three iterations.</p>	<p>Players have to discuss and reach a unanimous decision about the ranking of the items.</p> <p>Predefine positive/negative opinions about individual items are used by the robot to provide feedback.</p> <p>Wizard’s strategy used to i) keep the robot involved in the discussion, ii) answer directed or open questions and iii) make statements.</p>	<p>Furhat has a back-projected human-like head and incorporates speech synthesis, facial animation (lip and eyes movement, non-verbal gestures) and a robotic neck.</p> <p>Head pose detection was added by using the Kinect.</p>	<p>Three: two human players and one robot player</p>	<p>The robot attracted different head pose patterns from humans during turn changes. Symmetry in behavior can be used as a target metric to evaluate progress.</p>	<p>[30]</p>
<p>Alice R-50^a (Renamed Mina)</p> <p>Nao Robot^b (Renamed Nima)</p> <p>Woz Interaction & Controlled</p> <p>Mediator</p>	<p>Healthcare and Assistance</p> <p>Robot-assisted intervention on two twin brothers with autism. The aim of the study was to explore possible improvements inimitation, motor and social skills, eye contact and turn-taking.</p>	<p>A suite of therapeutic games that included:</p> <p>i) Game for teaching imitation and motor skills by robots to children through group exercises and dances.</p> <p>ii) Robot teleoperation using a external interfaces as remote controllers.</p> <p>iii) Recognition Game: Classification of animals and fruits by pointing to different baskets on the screen.</p> <p>iv) Virtual xylophone game</p>	<p>i) In the imitation game, the humanoid robot performs a movement (e.g., one-leg balance) and ask participants to do the same action.</p> <p>ii) One player teleoperates the robot and provides a specific gesture to imitate; the second player imitates the robot position.</p> <p>iii) Animals, fruits, places and objects are displayed on the screen, players use they gestures to play the game. Consecutively, the robot imitates the player’s gestures.</p> <p>iv) The robot plays specific notes with the xylophone and then, turn by turn, players have to imitate the movement and sound.</p> <p>Whether the child completed the task correctly or not, the robot provided verbal reinforcement and applauds for encouraging participants.</p>	<p>Alice R-50 and Nao robots were complemented with the Kinect sensor and the Haptic Phantom-Omni interface used to capture the desired actuator commands to be translated into the robot.</p> <p>Screens were also used to support gameplay.</p>	<p>Three: two humans (one child, one parent/therapist) and one robot player.</p>	<p>All participants’ autism severity decreased after the course of the program.</p> <p>Joint attention, gaze scores toward the robot, and verbal communication of the paired-groups increased significantly over the treatment time</p>	<p>[78,79]</p>

(Continued)

Table 1. Continued

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
SPRITE Robot ⁴ (renamed Kiwi) Autonomous Active player and moderator Executor	Healthcare and Assistance Socially assistive robots to improve the social well-being of older adults by supporting interactions within family members (older adult, adult, and children)	A set of four tablet-based games were designed, including rule-based games and open-ended creative games. i) Go Fish (structured): players work as a team, playing against the robot. The goal is to obtain books of a single card value in all four suits by asking each other for cards. ii) War: turn-based game, players place cards face-down from their deck to a center area. The player with the highest card wins. iii) Dance Dance Robot: is a choreography game in which family members, as a team, dragged and ordered tiles representing dance movements for the robot. Then, the robot performs the dancing. iv) Scrapbooking game: open-ended activity where family members together decorate an image while the robot observes and makes reinforcing and positive comments.	i) Players use a set of cards and try to complete the book of the same card value; they ask the robot if they have or not the card they need. While playing the Go Fish game, the robot commented on its performance and to engage in dialogue relevant to the game. ii) Players play with their own cards. The deck is equally distributed face-down among players, who play by turns placing cards in the center area. The robot is a competitor and the family members are also competing with each other. While playing the Go Fish game, the robot commented on its performance and to engage in dialogue relevant to the game. iii) Players use tiles representing dance moves for the robot to create choreographers. While dancing, the robot makes a variety of positive comments (e.g., 'Yeah!, Move it!') iv) Players start with white space and images of robots to drag and drop into the scene. A set of objects (e.g., hats, hearts, suns, moons) allows personalizing the design by overlapping the objects in scene.	SPRITE is a tabletop socially assistive robot with an expressive face displayed on a mobile phone. SPRITE's outer appearance, face and voice are customized to the application by using a bird-like design. Child-like voice is used using the Ivona text-to-speech software. SPRITE uses a wheeled cart and table. USB cameras were used for external face tracking, and a 3D depth cameras were used for skeleton tracking. Headsets with microphones were used to facilitate the communications between the players and the robot.	Four: three human players (older adult, adult, child) and one robot player.	Exploratory study revealing important insights on users' priorities for in-home deployment of socially assistive robots, as well as preferences about the activities, appearance, and behavior of the robot.	[71]
Nao Robot ⁵ WoZ Interaction Active Player, Tutor	Training Robot as a social character to engage children in a task. A tangram game was used to investigate the effect of the robot as a peer or tutor on children's task engagement	A Tangram game consisting of a set of 7 geometric-flat wooden pieces was used. In Tangram, players are encouraged to solve puzzles by organizing the pieces to create specific shapes based on a given silhouette.	Eleven verbal and nonverbal behaviors we designed to: i) regulate phases of the task, ii) provide information about the state of the task, iii) support the attention of the participants iv) provide reinforcement and support, and v) provide reward. Children were exposed to three Tangram challenges of increasing difficulty. The puzzle pieces were divided between the children to foster collaboration. Distinctive features of speech, gestures, positioning, and posture were used for the peer and tutor modalities. Specific gestures for both the tutor (e.g., pointing, presenting and head nods) and the peer (e.g., indication and surprise) were used to aid the interaction.	The Nao Robot was remotely controlled by a script operated by the researcher. A task-dependent flow was used to organize the set of behaviors to be followed by the robot. Three external cameras were used to record the sessions. A conventional Tangram with wooden pieces was used.	Three: two human players and one robot player	In the peer character condition, children paid attention to the robot and the task for a more extended period of time and solved the puzzles quicker and better than in the tutor condition.	[98]
SPRITE Robot ⁴ Autonomous Active Player and Moderator	Entertainment Robot as a moderator in a group interaction centered around a tablet-based assembly game. The study focused on exploring algorithms to balance performance of players in the game.	Cooperative game inspired in the SpaceTeam game where players have to work together to complete tasks based on given abilities. The goal of the game is for the team to score as many points as possible by collaborating with the rest of the team members.	Players have to collaborate in creating pairs of colored shapes from gray squares. Players sit in front of an individual angled tablet that displays the game interface visible only to that user. To complete the mission, players are asked to help other players by sharing tokens that appear in the interface. The robot, playing as an active player, uses a moderation algorithm to help users by providing them information about capabilities or needs (e.g., to get a token, to know a property) as well as providing specific instructions on subsequent attempts.	SPRITE is a social robot that uses a mobile phone to display simple facial expressions. It uses a dragon-like costume covered by soft fur, and it has a 10 cm range of motion. External tablets were used to display the game interface and touch screen was used for the interaction. Three USB cameras were used to record participants' faces while headset microphones were used to obtain audio recordings.	Four: three human players and one robot player.	An evaluation study showed that the different algorithms created for the robot to support gameplay influenced both task performance and group cohesion.	[70]

(Continued)

Table 1. Continued

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
<div>Ranger Robot^a</div> <div>WoZ Interaction</div> <div>Active player (collaborative)</div> <div> </div>	<div>Training</div> <div>A robot, remotely controlled, collaborating with children to play a tiles collecting game. The study objective was to study players reactions when the robot exhibited different behaviors (disobedient, lost, clumsy) while interacting with a dyad of children.</div>	<div>In the game, children and robot have to collaborate in order to assemble shapes using domino tiles spread out in the room. While children were actively searching and assembling the tiles spread over the room, the robot was helping them on transporting the tiles from one place to the other.</div> <div>A 14 runs game was played using the Domino tiles game.</div>	<div>Players have to collaborate with the robot in order to succeed in the game. One of the players, the searcher, has to collect domino tiles spread over the room and hidden behind beanbags. The receiver player assembles the tiles and decides for the next tile to fetch.</div> <div>The robot receives the tiles from the searcher and delivers them to the receiver player. At each turn (collect, transport, deliver), the robot exhibits experimental behaviors called correct, lost, disobey and mistake. Sounds, lights and specific trajectories are used to reflect the desired behavior in the robot.</div>	<div>Ranger is a wooden toy storage box equipped with wheels, inertial and proximity sensors, wheels, led panels and sound speakers.</div> <div>An external playmat and a tent were used to ambient the scenario. A Wizard control station is used to remotely control the robot and its behaviors.</div>	<div>Three: two human players and one robot player</div>	<div>An initial preliminary evaluation with 4-5 years old children revealed interesting findings in the sustained engagement level, particularly when the robot exhibited misbehaviors.</div>	[42]
<div>Emys robot^b (heads)</div> <div>Autonomous</div> <div>Active player (cooperative, competitive)</div> <div> </div>	<div>Entertainment</div> <div>Two robots and two humans are challenged to play a cards game. The objective was to explore human behavior differences when robot goal orientation (cooperative or competitive) and player role (partner or opponent) changed.</div>	<div>Participants played a Portuguese card game Sueca with three other players: another human participant and two robots. The goal of the game is for teams to score higher than the other by doing combinations of cards during the rounds. Human players played first with their human partner and then with the robots in cooperative or competitive modes.</div>	<div>Players have to team in pairs either with a robot or a human partner. Participants take turns playing as partners to each of the other three players in a hidden-information game. Players cooperate with their partners to get the highest score. Robots assumed more cooperative or competitive roles by activating pre-programmed utterances. Sueca is played with a classic french deck, each player starting with ten cards.</div>	<div>Two Emys heads were programmed to interact autonomously, displaying gaze behaviors, emotional expressions and speech. Robots are equipped with a repertoire of 840 utterances, triggered by game-related events and accompanied by congruent gaze and facial expressions.</div> <div>An external multi-touch game table and a French deck of cards with fiducial markers were used to aid the gameplay.</div>	<div>Four: two human players and two robot players.</div>	<div>Participants directed more behaviors towards partners than opponents. Players in the role of opponents directed more socioemotional behaviors towards robots than towards the other human players.</div>	[55]

(Continued)

Table 1. Continued

Robot Name, Robot Autonomy and Robot Role	Context and study objective	Game Features			Number of players	Main Findings	Ref
		Description and goal	Mechanics and Feedback	Technology			
Kaspar ^a Semi-autonomous Active Player Executor	Training A social robot empowered with novel tactile technologies is used to create playful scenarios to evaluate human-robot interactions in children with autism.	A set of different playful scenarios were created to evaluate case study examples for novel robotic skin interfaces and their role in human robot interaction. One child and one adult (parent, teacher, therapist) are the players: i) (Cause and effect) Players interact with Kaspar by touching different parts of its skin. The adult operates the robot (e.g., activating positive feedback) when needed whereas the child has to touch the robot in multiple parts and observe/react/learn from its autonomous responses. ii) (Sequencing) Kaspar points with one of its hands to a sequence of its different body parts. Players have to activate the sensors by touching Kaspar in the pointed body parts following the sequence.	Games have different mechanics but similar feedback mechanisms such as body movements and postures, facial expressions and voice. i) Child player is shown how to operate the robot by touch and then using an exploratory approach, child operates the robot by touching it in multiple body parts. Kaspar feedback includes specific voice reactions (e.g., laughing and commenting when tickling) and body postures (e.g., sad posture when excessive force is used). The adult uses the remote control when needed to provide additional feedback (when child hits the robot in areas without sensors). ii) In a turn-based game, players have to follow a sequence of touching instructions previously provided by Kaspar in an imitation game. For each correct activation, Kaspar blinked eye lids and played reinforcing sounds. Similarly, the robot reacted with distinct audible feedback once wrong sensors were touched.	Kaspar can express emotions by using bodily (movements of the head, arms, torso) and facial expressions. It also can interact with humans using gestures. For this study, Kaspar was empowered with several skin patches made of distributed pressure sensors on checks, torso, left and right arm, back and palm of the hands and also soles of the feet. The robot could be operated by a remote controlled keypad.	Three: two human players and one robot player	Results from the cause and effect game allowed children with autism to explore simple motor manipulation and to engage in tactile interactions with the robot by taking the initiative. The sequencing game fostered a natural and socially engaging triadic interaction between the child, the experimenter and the robot.	[61]

^aPictures taken from original papers.

^bPictures labeled for reuse.

- (1) Robots: The first section included the name and picture of the robot mediating the game, the level of autonomy of the robot (e.g., Wizard of Oz, fully autonomous), and the robot's role (e.g., trainer, active player, or peer). The most popular robot used in the revised articles was the Nao ($n = 4$), which was used either with its entire robotic body or only with its torso. The SPRITE robot, which uses two different custom-built skins (dragon and stylized bird) was used in two experiments. Different versions of the robot Kaspar were also used in two of the reviewed papers. Other robots used include Corkscrew robot figurine, AIBO (dog-like robot), E-puck, Furhat and Emys robot heads, and the Range robot.
- (2) Context: The second section describes the context of the research, the final application where both robots and human players were involved. The two most popular scenarios were training and/or education games ($n = 6$) and entertainment applications ($n = 5$) mediated by interactive robots. Similarly, the use of robots to support healthcare activities ($n = 3$) such as psychological assistance was a popular application. Moreover, this category also included a brief description of the research problem under investigation, highlighting specific keywords commonly used in each research article.
- (3) Game features: This section encompasses specific information regarding game design elements used to foster interactivity between robots and human players. An initial description and goal of the game were used to provide a context and explanation of the basic objective of the game as well as the game type (e.g., turn-based). Mechanics and technology were covered as two elements consistently described and used in the HRI scenarios proposed in the articles. Aesthetics and story/narrative were not consistently described across the manuscripts. Together with the game mechanics, we described the feedback mechanism used by the robot and games to inform people about their performance and

Fig. 2. Robo Ludens taxonomy specifying the categories related to the robot's abilities.

overall gameplay. Describing the feedback paradigm is important, since it allows the identification of important elements of the socially interactive robots such as sensors and perception modalities. Moreover, we also included details related to interfaces and physical setup in the technology section, aiming to bring a holistic understanding of the technological elements used in each HRI scenario.

- (4) Number of players: The amount of both human and robot players was described in this section, highlighting (when necessary) specific roles of the players such as tutors or assistants.
- (5) Main findings: This section reports the main insights found after applying and experimenting with the robot(s) and human player(s), revealing the scientific value and results of using multiplayer games with socially interactive robots. The main findings are reported in a simplified manner without specifying details but reporting the overall big picture of the research.

4 ROBO-LUDENS TAXONOMY

After reviewing the HRI scenarios where gameplay was included as a medium to create a multiplayer experience, we propose a taxonomy called Robo Ludens,¹ which aims at explaining the different categories that should be considered when designing games for HRI scenarios. Beyond the reviewed papers, the taxonomy expands on other possible sub-categories and definitions that should be considered when defining the integration of both robots and games. Therefore, there are two main principles underlying the classifications carried out in the Robo Ludens taxonomy (see Figure 2 and Figure 3): the robot, its role, appearance and motor abilities as well as the game characteristics: game mechanics, application, as well as the sensing capabilities and feedback modalities that are strongly dependent on the robot.

4.1 Taxonomy Categories

4.1.1 Robot Role. Depending on the particular HRI scenario, robots can play different roles while encouraging people to interact with the games. Five are the main categories found for this characteristic:

¹www.roboludens.ca.

Fig. 3. Robo Ludens taxonomy specifying the categories related to the game characteristics.

- (1) Active player: Robots can assume the role of an active player when designers want to explore reactions or behaviors of human players to robot dynamics such as turn-based or decision-making. Particularly, in multiplayer gameplay, specific player dynamics allow the creation of robot roles such as cooperative, collaborative, or competitive. Cooperative gameplay means the players have operated together towards achieving a common goal by, for instance, dividing the work among the co-operators. Collaborative learning by means of serious multiplayer games [92]. For instance, the Emys robot cooperates with players by teaming with individual subjects and trying to score together the highest amount of points by combining their efforts at the end of the game [55]. In contrast, collaborative gameplay requires a more cohesive relationship between players towards achieving a shared objective [92]. The experiment using Ranger the robot is a clear example of collaboration in a multiplayer game where the game progress is not possible without a proper articulation of the activities carried out for each player [42]. Kaspar was also used to foster collaboration among children with autism, showing the potential of social robots to boost collaborative behaviors [88]. Finally, robots can also be excellent competitors when empowered with enough information about game rules and others. Only one of the reviewed papers used two Emys head robots to compete against two human-players [55].
- (2) Trainer, Tutor/Mentor or Teacher: Research has shown that using robots to support learning processes can provide positive experiences and improve performance in learners [63]. One of the most popular roles of robots in multiplayer games was using robots to support the learning process by training, tutoring, or teaching human players. Teaching involves the process of aiding learners to acquire knowledge or competences through a learning process. Tutoring or mentoring is a more specific type of teaching [89] where the robot's primary purpose is to instruct and guide learners by focusing on a specific subject, customizing the educational process. Nao was used as an empathetic tutor to instruct children on the design principles of sustainable cities [4]. Finally, a trainer can be more associated with a robot that trains the learner in one-on-one or small group interaction. The use of Nao as a psychologist assistant is a good example of a trainer/coach role where the robot was teaching children relaxation techniques in a small group setup [2]. Although robots cannot provide the level of sophistication of humans in terms of assisting learning, applications of social robots in education beyond teaching have also included peer-to-peer relationships and robots as learners (or novices) [7].
- (3) Moderator or Mediator: Robots can provide guidance and promote engagement for humans to play games. AIBO, a dog-like robot, was used to mediate the online gameplay in human-human interactions, showing a hybrid paradigm for multiplayer interaction [56].

Also, the robot SPRITE was used to engage players in the Go Fish game by commenting on their performance and using relevant facts for the gameplay, thus serving as a game mediator. A special case of this category is using robots as referees, which is a specific way to mediate the gameplay; the Corkscrew robot, for instance, was used as a referee, since it was in charge of defining the winner by sensing reaction times [87].

- (4) Executor or performer: A unique role that robots can assume when engaging players in games is to perform or execute commands in a controlled or teleoperated fashion. Studies have shown that human embodiment can be achieved when human operators are engaged in tasks executed by robots, so achieving an ownership illusion [3]. Similar to conventional videogames, this ownership with the virtual representation (avatar) can boost the game user experience and the empathy with the controlled agent [67]. The E-puck robot was used to execute the commands from a group of children looking to improve their social interaction [6]. Alice R-50 and Nao were also used as teleoperators, where one of the players was controlling the robot to provide a posture to be imitated by the other human player [79].
- (5) Bystander: While present in a physical space with humans, robots can provoke a wide range of emotions and impressions even without interacting with them [34, 43]. In social video gaming, bystanders can be defined as participants that are observing others while playing games without interfering directly or indirectly in the gameplay [15]. Although no example of using robots as bystanders in multiplayer games was found in the review process, the effects of robots as bystanders in non-gaming multi-user scenarios have shown how robot's behaviors affected subjects' participation in a conversation [52].

4.1.2 Appearance. From a human perception perspective and considering the impact of the first sight, it has been shown that the visual appearance of a robot affects user's expectations when they interact with it [93]. From the gameplay perspective, the morphological characteristics of the robot also help in shaping the creation of interactive experiences suitable for the game interaction (e.g., game feedback, game performance sensing). From the initial four morphological categories proposed by Fong et al. [17], our taxonomy proposes six paradigms that have been widely reported in the HRI literature, which consider functional and behavioral characteristics of social robots:

- (1) Zoomorphic: related to the attribution of characteristics from living creatures to robots. From an HRI perspective, the relationship owner-pet is sometimes preferable to human-human relationships to avoid suggested effects such as the "uncanny valley" as well as due to its simplicity [17], which can decrease the likelihood of having unrealistic expectations of the robot's abilities. AIBO, the dog-like robot, is a good example of zoomorphic robots used in multiplayer HRI scenarios.
- (2) Anthropomorphic: related to the attribution of human-like characteristics to objects (e.g., robots) with the ultimate goal of aiding the rationalization process of their actions [16]. The SPRITE robots with their friendly and emotive face is a good example of this category.
- (3) Original or artistic: This category encompasses robots that have unique features and cannot be included in any other category. These are robots that can express artistic feelings and emotions as well as to integrate original metaphysical attributes as products of the designer's imagination. The Corkscrew robot is an example of an original robot.
- (4) Functional: Beyond biologically inspired robots (e.g., zoomorphic, anthropomorphic), the approach of "functionally designed" allows a more objective and straightforward design process by reflecting the task the robot should perform, considering operational as well as practical objectives [58]. In terms of game elements, this has a direct connection with the game mechanics and technology, the two elements that are more associated with the

functionality of the game [67]. The E-puck and Ranger robots are good examples of functional robots wherein their design aspect is highly influenced by the tasks the robots must perform (e.g., moving elements).

- (5) Mechanoid: This category describes robots with relatively machine-like appearance [90]. Research has shown that humans tend to treat mechanical-looking robots less politely and more assuredly than human-like robots [26]. Emys robot is an example of a mechanoid robot that, despite having elements related to living creatures (e.g., eyes, nose, mouth), its appearance is predominantly mechanical.
- (6) Humanoid: robots that are not realistically human-like in appearance but are perceived as a robot by human interactants. Although they have human-like features such as head, facial features, and lower/upper limbs, they are usually incorporated as a way to stylize and produce an aesthetically pleasing experience. Nao and Kaspar are good examples of humanoid robots, both covering the two different approaches of human likeness (Kaspar) versus a more cartoonish/simplified appearance (Nao).

4.1.3 Motor Abilities. The capability that a socially interactive robot has to physically move is a unique feature of embodied robots that facilitates attention-grabbing and empowers physical presence to play a meaningful role in HRI scenarios [17]. In the review, we identified two different motor capabilities that define how the robot is able to move in the physical space and interact with reachable objects: in place movement, in space movement.

- (1) In-place movement: Robots that are physically fixed normally have limbs or extremities that allow reaching/manipulating distant objects or players to interact with, without the need of physical displacements. Robotic heads such as Furhat or Emys are normally restricted in terms of movement, but they are equipped with several sensors for facial expressions to compensate. Even though the SPRITE robots are equipped with lower limbs (e.g., legs), they are also considered as in-place movement robots, since they cannot have displacements from their initial position. Board, card, and narrative-driven games are more suitable for in place movements.
- (2) In-space movement: Robots that are equipped with wheels, legs, and other mobility artifacts can change their physical position and propose interactions that may elicit similar responses from human counterparts. Imitation games, as well as hide-and-seek or object collection games, were proposed in the multiplayer scenarios reviewed. For instance, Ranger the robot collaborated with two children players in a tile-collecting game by transporting the pieces from one place to the other [42].

4.1.4 Game Mechanics. Game mechanics can be considered as the interaction core of the game, enclosing relationships and actions that remain when all the other game design elements (e.g., technology, aesthetic, story) are removed. Although there are not clear/universally agreed-upon categories of game mechanics, this taxonomy establishes five different core mechanics wherein each of the examined papers would fit in one or more of them. Good games are normally structured around a very limited yet well-defined amount of game mechanics [1].

- (1) Imitation: Players are encouraged to mimic or imitate behaviors (e.g., postures, talks, facial expressions) of other players or mediators to score in the game. Imitative behaviors have been widely used for learning appropriate behaviors, particularly in children with special needs (e.g., autism) [66] and therapeutic scenarios [22]. Nao was used to illustrate children with cancer on how to deal with pain and stress through respiration and meditation techniques [2]. In contrast, the same robot was also used to imitate human players' gestures in a game aiming to educate children with autism in social skills [79]. It is worth

- noticing that the robot can play both the illustrator (e.g., the one creating the behaviors to be imitated) and the imitator roles in the gameplay based on turn-taking dynamics, as shown by Kaspar in the imitative collaborative game [88] or the sequencing game [61].
- (2) Guessing: Players are encouraged to estimate or guess something from another player or mediator. Card-guessing or word-guessing games have been widely used in HRI scenarios involving social robots and children with [29] and without special needs [35, 69]. Nao was used by psychologist assistants to encourage children with cancer to remember or guess past situations by giving human players recorded audio clues from their previous interactions [2].
 - (3) Task completion (cooperative, collaborative): Players create teams and are challenged to complete tasks that will impact the final score. As a game mechanic, task completion can use rewards to compensate players for achieving their end (e.g., badges, specific robot behaviors [56]). Particularly in HRI scenarios using multiplayer games, adding elements that foster togetherness and comradeship in players (e.g., collaborative or cooperative) while completing tasks has been found as a meaningful way to promote cohesiveness [76] and collaboration [88] among children. This game mechanic is very important in multiplayer games when more than one human player is involved, since the collaboration/cooperation and competition with or against other human players can drastically change the experience when compared to artificial agents [74]. The robot Kaspar was used to encourage pairs of children with autism to pose for a certain period of time to win the game and be rewarded (e.g., victorious music).
 - (4) Teleoperation: Human players are invited and instructed to teleoperate a robot for carrying out specific actions. The relationship between the human operator and the robot allows a translation of players' intentions directly to robots' actions. Nevertheless, teleoperation has not been widely explored in multiplayer games for HRI. The robot Alice R-50 was used to encourage one of the human players to imitate a robot that was teleoperated by the other human player [79]. Also, the dog-like AIBO robot was used to mediate the teleoperation of its virtual representation and reward participants in a maze game [56].
 - (5) Reaction time: Players are encouraged to complete game challenges in a limited time and the most responsive or fastest player in reacting to specific stimulus is often rewarded. Time is one of the most often used game mechanics that allows players to have a sense of how the game is progressing, the length of the gameplay activities, and when the game is going to end [67]. Reaction time (and its variability) is also an important human factor that can reveal important aspects of cognitive readiness and serve to inform about cognitive-motor decline in gaming scenarios [81]. The Corkscrew robot implemented reaction time as a game mechanic by rewarding the fastest player as the winner of the round [87].

4.1.5 Application. Although games have been intentionally created as a medium to entertain humans, there is growing evidence of the use of applied games (also called serious games [49]) in areas such as training or healthcare. Based on the reviewed papers, four are the application areas where social robots have been used in multiplayer HRI scenarios: entertainment, educational, training, and assistance.

Entertainment: Besides functional support or assistance, socially assistive robots can provide social wellbeing in the form of entertainment through games. Research has shown that there is a meaningful and measurable value in using social robots as tools to entertain and challenge participants in a wide variety of audiences [19, 32]. Two robot heads were used as entertainment vehicles in multiplayer games. Two Emys played a card game with two human players while exploring differences in cooperative and competitive

modes [55] while the Furhat robot was used in a team-building game with two human players to examine behavioral patterns [30]. Similarly, SPRITE the robot was used in a team-building game with children looking at encouraging team cohesiveness and participation through entertainment games with fantasy-like themes. Finally, while being the referee, the anthropomorphic Corkscrew robot uses a reaction time game to entertain a group of four human players [87].

- (1) Educational: Social robots have been widely used in an educational context, showing to be effective at increasing cognitive (e.g., learning gain, completion time of tests, number of attempts needed for correct response) and affective outcomes (e.g., persistence, empathy) [7]. Furthermore, serious games for educational purposes have also gained a lot of attraction, revealing positive benefits in cognitive gains and increases in positive affective toward learning [40]. For instance, the torso of the Nao robot was used as a tutor for fostering a sustained collaborative and educational interaction among primary school children [4], so combining both a serious game for education (Enercities) and a social robot to carry out the knowledge transference.
- (2) Training: Social robots have also shown proficiency in training scenarios where robots are programmed to impart special skills or behaviors to human subjects. From training programs to support children with special needs (e.g., autism) [7] to cognitive training for people living with dementia [85], social robots have revealed outstanding skills (e.g., motivate learners) to carry out training sessions with learners. For instance, Nao was used to train children on task engagement through a puzzle-like game (Tangram) showing interesting comparisons between different roles of the robot (e.g., peer, tutor/trainer) [98]. Also, Ranger the robot was used to train collaborative behaviors among children while the robot itself was exposing different unexpected behaviors (e.g., disobedient) [42].
- (3) Assistance: Finally, a more specialized application for social robots and games is to use them as assistive technology, able to maintain or improve an individual's functioning [11]. When it comes to games and social robots, research in socially assistive interactive robots has shown benefits in assisting therapeutic interventions for children with autism [12] and cognitive interventions in older adults [45]. Nao, for instance, was used as a playful psychologist assistant to aid children with cancer to deal with their pain [2], and Alice R-50 was empowered with a set of three therapeutic games to assist children with autism in imitation, motor and social skills, eye contact, and turn-taking [79].

4.1.6 Sensing Capabilities. To provide compelling, playable and interactive game mechanics, social robots need to be empowered with sensing technologies able to close the game loop between the player and the system. This means the robot should, somehow, be aware of the player's actions to react accordingly and keep the game challenge. In the case of conventional videogames, handheld controllers allow sensing button-pressing actions; thus, the system can respond accordingly. Researchers on social robots and games have instead avoided the use of regular controllers and have made use of the different sensing modalities embedded in the robotic systems to capture players' actions and close the game loop. Particularly, in the field of multiplayer games with social robots, we found gesture and posture recognition as well as touch or tactile sensing capabilities the most popular among researchers to collect player's responses and sense the space to close the game loop. Other sensing capabilities have been adapted to the experimental setups to collect data from players and to carry out a post-session analysis. Here, we refer only to the "game interfaces" used to communicate human player's actions with the robot in real-time as well as using the sensed information to adapt the gameplay.

- (1) Gesture, posture: Detecting specific player's movements and poses has been useful to map motion to game events aiming to attract player's interest and train things such as gross and fine motor skills [18, 96]. Social robots can use both computer vision algorithms as well as external sensors to sense specific gestures and postures from players while interacting with games. For instance, Kaspar used external game controllers (e.g., Wiimote) to detect children's postures and keep them engaged in a posture imitation game [88]. The Kinect sensor was also used to interface player's movements with the Nao robot to engage children in a motor imitation game in children with autism [79].
- (2) Facial: Human face can be used to inform social robots about specific player's states to communicate expressive behaviors. Although facial expressions have been used as input in regular videogames (e.g., affective games or emotionally aware games [8, 41]), facial recognition has been mainly used for post-experiment human emotion and affection understanding in HRI scenarios as well as to display affective information [48]. For instance, Nao was complemented with depth cameras that registered facial information from children in a collaborative educational scenario to explore behavioral data of players [33].
- (3) Speech: Incorporating capabilities to sense and recognize human speech can help to understand three variables: who the speaker is, what the speaker said, and how the speaker said it [17]. Although regular videogames have widely explored the use of voice commands as input mechanism [73], autonomous interaction through speech recognition techniques has been minimally explored for social robots; particularly, it has been explored in those aiming at helping children in healthcare and therapeutic contexts [13]. Furthermore, three approaches to process the speech information are the most common in HRI: speaker tracking, dialogue management, and emotion analysis. The Robot Furhat [30], for instance, integrates speech synthesis technology to create more human-like conversations, whereas the SPRITE robot used a third-party software tool to carry out speech-to-text analysis to better understand older adults' preferences in using social robots for fostering social interactions with their families [71].
- (4) Touch (screen, embedded): Technologies for capturing tactile interactions between social robots and human players can be simplified into two categories: (external/integrated) screens and embedded touch sensors. In terms of game interaction, these technologies propose two different paradigms: Whereas screens can be used to allow users to input commands for straightforward communication with the robot, the touch sensors provide information regarding contact pressure points, which are informative about specific actions between players and robots (e.g., touching in specific areas, hugging, grasping) as well as internal human states [96]. In multiplayer HRI gaming scenarios, external screens have been used as a way to facilitate sensing game input from human players. The robots Kaspar, Nao, Alice R-50, and SPRITE were interfaced with touch screens to capture the players' responses and improve the game interactions.
- (5) Gaze tracking: Gaze is an indicator of what a player is looking at or paying attention to and can be quantified through head orientation and eye orientation [17]. To better understand players' behaviors, particularly how people are playing, tracking the gaze can be handy information for the robot, since it allows fine access to the human brain functions (e.g., attention, scene perception [86]). Nao was used as an empathic tutor empowered with a perceptive intelligent layer capable of use gaze tracking to inform the game module and autonomously manage time and expressive resources [4].
- (6) Proximity: Sensing how close the robot is to an object or a human player can be informative not only of the surrounded environment (e.g., to improve navigation, space perception) but also about emotional states of players and their willingness to interact with the

robot [42]. The robot Ranger was equipped with proximity sensors to facilitate navigation through a physical space to collaborate with human players in solving a puzzle [36].

4.1.7 Feedback Modality. Feedback allows players to get a sense of how they are doing while playing the game in terms of progress and performance. Feedback can mean many things, such as rewards, punishments, instructions, encouragement, challenge, or simply judgment [67]. Socially interactive robots should be able to send readable social clues such as clear and consistent feedback of its internal state, which in the case of games, this can be information regarding game progress and responses to players' actions. Feedback can also be informative about specific robot states (real or fake ones) such as intentions or goals [17]. Through the review, we identified six types of feedback named screen-based, speech/sounds, haptic, facial expressions, body language, and lights that social robots used to interact with human players. In one way or another, the feedback mechanisms were used to display specific clues to the players and facilitate the human-robot interaction through the gameplay.

- (1) Screen-based: Screens are one of the most straightforward means to communicate information with human players due to the fact we spend a considerable amount of time per day watching screens (e.g., PCs, mobile phones, TVs). Based on the papers reviewed, screens were mainly used for two different purposes: as a game interface for players and robots, and as an emotional window to display affective clues of robots. Nao and Kaspar were interfaced with external screens to display visual feedback elements of the games to facilitate the interaction and capture the player commands/inputs by using touch screens [4, 88]. The robot SPRITE used two different screens: one for displaying facial expressions, and external screens were used as game interfaces for human players [70].
- (2) Speech, sounds: Speech is a highly effective method for communicating game tutorials, progress, and decisions. Using voices or sounds to reinforce game elements and provide feedback to the players is an extremely powerful way to keep players engaged while interacting with games [27]. Socially interactive robots have been successfully used to tell stories and engage audiences for educational and entertaining purposes, showing convincing persuasive capabilities in HRI scenarios [18, 23]. Nao was used to respond to questions regarding cancer treatment procedures and medical devices from children with cancer by using the internet connection as well as playing short dialogs from a previous therapeutic session, thus proposing a guessing game [2].
- (3) Haptic: Vibrations, forces, or motions that can create experiences of touching something or someone have been used in socially interactive robots, showing the potential to significantly improve the intuitiveness in HRI scenarios [72]. Games and virtual training programs have been taking advantage of haptic technologies to improve realism in complex training scenarios for medical education and surgical skills training [21]. Two different examples were found in the multiplayer games in HRI scenarios reviewed that used haptics as feedback mechanisms [87]. The Corkscrew robot used vibrations in the guessing game, so the first player in detecting the vibrating object would be the winner. While using the Nao and Alice R-50 robots as therapist assistants, researchers used a haptic interface and feedback to allow human players to command the robot and translate their intentions [78] (e.g., haptic feedback was used as an extension of the other feedback provided by the robot).
- (4) Facial expressions: Robots able to express emotions through facial gestures have been using elements such as mouth, cheeks, eyes, eyebrows, and forehead to convey complex behaviors (e.g., expressing "I don't know") [17]. Robotic head systems such as Emy and Furhat use advanced technologies to create facial animations, since their interaction

paradigm requires things such as eye contact and conversations with human players. Indeed, both Emys and Furhat were used for card/object collection games, which normally require interpreting facial clues to infer players' behaviors and intentions. Contrarily, humanoid robots such as Nao or Kaspar can use facial expressions to complement the movement of the upper/lower limbs as well as other body postural behaviors, which can be useful for imitation or guessing games.

- (5) Body language (posture and gesture): Nonverbal communication is often conveyed by using other parts of the robot body, such as upper and lower limbs. Robotic movements often tend to elicit automatic imitation [59]. Imitation games were proposed for the Nao, Kaspar, Alice R-50 robots, considering their capacities to express emotions through body language.
- (6) Lights: Robots with limited or no facial or body expressive technologies often use visual clues such as lights and moving parts to capture the attention of human players while mediating interactions. Anthropometric robots such as the E-puck or the Ranger are equipped with lights used to metaphorically express emotions or reflect the desired behavior. Although it may require some cognitive processing from the human player perspective to understand the feedback, it has been shown in HRI scenarios that by finely tuning elements of the visual stimulus, such as color, intensity, shape or visual texture, different human responses can be elicited [96].

In summary, the Robo Ludens taxonomy intends to encompass interaction paradigms, design considerations, game characteristics, and categories as well as robot capabilities and their relationship with the players and the expected human behaviors. Although the taxonomy was created based on HRI scenarios for multiplayer setups considering the richness and dynamics of the interaction when having more than one human player involved, the principles here described can also be extended to other simpler scenarios (e.g., games involving only one human player). The two categories presented (robot, games characteristics) are intrinsically connected and some of their sub-categories can be grouped in one or the other. Especially, the sensing capabilities and the feedback modality have shared components in most of the reviewed papers. Therefore, Figure 4 presents how the sub-categories are interconnected considering both the robot and game's characteristics.

5 DISCUSSION

This scoping review identified 16 studies that explored the use of socially interactive robots in multiplayer games involving two or more human players. The embodied robots used and games proposed revealed the diversity of the HRI approaches, how emerging is the convergence between games and social robots, and the potential of using them for applications such as training or entertainment. In the following, we propose a discussion that encapsulates the main findings, highlights, important considerations, and literature gaps:

5.1 Why do you need a robot in this game?

Different socially interactive robots were used in the included papers for the scoping review. From humanoids to anthropometric robots, their capabilities to sense the world and move around defined critical aspects of the multiplayer games created. Seven experiments included external screens to aid the gameplay and facilitate the communication with human players. An interesting aspect to explore is the meaningfulness of the role of the robot in the proposed interaction with the game. Are simple touch-screen devices or game consoles able to deliver similar enjoyable experiences than robots? Maybe the most common scenario where both robots and external input devices have been combinedly used is for teleoperation tasks [25]. Games are already a very popular medium

Fig. 4. Relationship between the sub-categories proposed for both the robot and the game characteristics in the Robo Ludens taxonomy.

that engage millions of players around the world. Embodied robots, instead, often struggle to massively reach specific audiences and engage them in the long term. We believe both games and robots can significantly contribute to the creation of highly engaging experiences for specific audiences and targeted applications [46]. Further analysis of the robot's roles and its importance to mediate and provoke enjoyable and playful experiences is necessary to better understand the synergy between games and socially interactive robots. Moreover, when it comes to evaluating the role of the robot in the multiplayer gaming scenarios, the lack of control conditions that allow the evaluation of players' responses to the games and robots separately does not allow a comprehensive understanding of causalities and behaviors.

5.2 Unbalanced Games and Uncomplete Documentation

The games created in the above-mentioned HRI multiplayer studies unbalanced important aspects of game design such as story or aesthetics and are heavily focused on technology. One of the aspects that can contribute to this is the necessary focus on the technological capabilities of the robot, which tend to limit important game design elements such as game mechanics. Also, there is often not a clear match between robots' skills and game design choices. For instance, robots' capabilities to talk and express gestures and body language were rarely used to complement game mechanics with creative stories. Also, robots that were equipped or interfaced with screens implemented relatively "simplistic" aesthetics, which did not contribute to the game cohesiveness and correct balance. Therefore, to better balance games used in HRI experiments, we recommend designers to (i) look critically at the games and try to identify regarding mechanics, story, aesthetic, or technology, which element is predominantly and, maybe, excessively used to drive the experience, to then create ways to complement it by addressing the other elements; (ii) playtest multiple times before the research trials; (iii) use available tools and techniques to balance your game (e.g., set of cards or lenses with key design recommendations [67]). In particular, we believe researchers in the field of HRI should pay more attention to the story and aesthetics of the games and avoid overloading the player's experience heavily with technological aspects. It is worth noticing that

certain audiences such as children and teenagers are extremely visual-driven participants, and aesthetics and attractive user interfaces can play a crucial role in creating engaging experiences [77]. Moreover, it is important to notice that previous research has shown how the robot appearance affects the subjective perception of users towards interaction aspects such as enjoyment to the game [38], perception of sound [36], sense of intentionality [53], and type of task (e.g., teaching, guide, entertainment and security guard) [44].

Finding the specific game elements in the papers was a consistent challenge throughout the scoping review process. A more descriptive and precise description of game elements for HRI scenarios can be achieved through (i) describing the game in terms of fundamental elements (e.g., mechanics, technology, story, aesthetics), (ii) adding subsections in the methodology to explicitly describe the game and its components, (iii) enriching the explanation by referencing popular games or mechanics that can lead to a better understanding of the gameplay and how the game is played. Last, preliminary research exploring the role of player types (e.g., Bartle taxonomy [67]) in the interaction with socially interactive robots has been neglected in the HRI literature. Knowing player characteristics and game preferences has demonstrated to be useful knowledge to explain the player's behaviors and decisions during the gameplay [82].

5.3 Game Design Process and Long-term Effects

After carefully reviewing the methods and procedures section of the included papers, we noticed that the game design process rarely implemented and/or documented an iterative prototyping process, a standard procedure in the game design field [67]. Playtesting game prototypes in the early stages is one of the most critical steps in the design of interactive games, since it allows detecting simple mistakes in the game elements that are not visible without testing with real players. For instance, simple playtesting sessions can be carried out to verify if human players are able to understand the game rules being described by the robot through its speech or if extra visual material is needed. For playtesting, it is recommendable to: (i) involve target audience in early stages of the design process, (ii) test individual features of the game as opposed to playtest multiple hypotheses (e.g., is the game theme adequate, is this game mechanic fostering collaboration), and (iii) incorporate the players' feedback and iterate fast [31]. We believe there is a need for more integrated and simplified development of robotic systems that can be used to speed up the prototyping of game design concepts. For instance, novel social robots could incorporate predefined routines for popular game mechanics such as guessing or teleoperation as well as detection algorithms to ease the recognition of individual tokens and boards that can be used to prototype games. Especially, multiplayer games, which are more complex to program and harder to balance when compared to single player experiences, can benefit from the development of more streamlined robotic/gaming systems and infrastructure that could accelerate the prototyping and create more meaningful experiences with robots and humans.

Furthermore, the long-term effects of interactive games with robots are underexplored; most of the included games were played for less than 15 minutes. This is a common limitation in HRI and serious games studies, where it is widely known that novelty effects can extensively influence players' responses and behaviors [67, 96]. Also, replay-ability is an important aspect of interactive games that allows investigating whether players are willing or not to continue playing the game after the first attempt, and this was not specifically addressed in the included papers.

5.4 HCI, HRI, and Game Design

More multidisciplinary teams and collaborations are needed to design games that are genuinely unique in combining HRI and multiplayer gameplay. For instance, researchers in the field of HCI and game design could provide meaningful insights about interfaces able to exploit robot

sensing capabilities and motor abilities to engage players without spending too much time on technological implementations (e.g., computer vision algorithms). Drum-like interfaces are good examples of gaming controllers that can be adapted to be used by social robots to foster enjoyable game experiences without spending too much effort in coding or digital electronics, since they can be used with commercially available games/interfaces [24, 33]. Another potential booster of a good game user experience with social robots can be using voice interaction and design patterns, and guidelines have already been proposed to better structure speech recognition techniques for specific game tasks, such as selection, navigation, control, and performance actions [3]. There are two other aspects in the field of game design that we believe are important to consider when designing playful experiences in HRI: (i) game genres and multiplayer gaming and (ii) game mechanics mapping to specific robot's capabilities. First, a taxonomy of videogame playing preferences showed action, sports, and cards strongly favor multiplayer experiences and also exposed that men are more likely to enjoy multiplayer gaming [83]. Second, some game mechanics are more likely to be suitable for certain robots' capabilities, and their impact in the creation of more enjoyable experiences for certain audiences is a fundamental aspect to consider to avoid monotony and boredom. For instance, learning objectives and game mechanics can be mapped beforehand to improve the impact and the effectiveness of a robot-aided intervention [5], or certain game mechanics can be used to foster specific skills or intelligences (e.g., linguistic, kinesthetic, musical) based on robots sensing/feedback capabilities [64].

6 LIMITATIONS AND FUTURE DIRECTIONS

Our review process and taxonomy design included several steps towards filtering and polishing the qualitative information from the selected papers. Some of the limitations we have identified are listed as follows:

6.1 Inadvertent Risk of Exclusion

Although the papers included in the review process were carefully selected and previously discussed by the authors, this review process has an unintended risk of excluding relevant papers that have been published covering multiplayer HRI gameplay scenarios. First, due to the large volume of papers and studies that had to be reviewed, the likelihood of omitting information or erroneously exclude some of them is high (e.g., one of the reviewers identified References [57, 68]). One of the main reasons for the high exclusion rate was because the search criteria identified robot interventions that did not necessarily include multiplayer scenarios, or the activities proposed when robot(s) and humans were interacting together did not satisfy the previously defined definition of games. For instance, several papers covered HRI activities such as storytelling, assistance, simulation, or conversational that are not considered as games [80]. Others provided some descriptions of HRI and game concepts or study designs without evidence of implementation [37]. One example covered a multiplayer game, but instead of having two or more human players, it was implemented using a triadic interaction between two humanoid robots and one human player [24]. Moreover, although some publications were explicitly including important keywords for this review, such as game or play, we also noticed that papers in specific areas (e.g., therapeutic, learning) do not necessarily use the word games, but terms such as "activities," "scenarios," or "tasks" instead. However, a closer look at those papers may reveal that, indeed, these activities are perfectly aligned with what a game is, but researchers were not defining them as such explicitly. This indicates the need to discuss differences in terminology across different research fields. HRI has been inspired from its beginnings by many research fields, such as HCI, psychology, and robotics, but game design has not featured prominently so far. Thus, the fact that some papers were missed in the course of doing a scoping review is evidence of this gap. Finally, we also found that the

same setup, robot, and/or game was used multiple times in different experiments, covering different research questions and target audiences. To avoid repetitions and maximize the diversity of the studies included, we have also filtered some papers we identified as repetitive in terms of the HRI scenario and game implementation.

6.2 Insufficient Information for Qualitative Analysis

During the review process, we also noticed that some papers included well-described scenarios and game elements for robot-assisted play; however, when trying to complete the qualitative analysis using the categories proposed, some papers were not sufficiently explicit or descriptive to allow deconstructing game elements such as goals or feedback. As pointed out in the discussion section, well-defined methods that describe and report gameplay studies (and any other study) allow manuscripts to gain visibility and it facilitates that the reproducibility of the results can be eventually achieved [20].

6.3 Lack of More Taxonomies in HRI and Games

It is worth to acknowledge that although other researchers have proposed taxonomies in the field of game design or HRI separately, the Robo Ludens taxonomy is unique in combining scenarios with multiplayer games and embodied robots. This uniqueness can be seen as a limitation, since no comparison or benchmarking analysis can be done, and this is partially due to the emergent nature of the HRI field and its combination with game user research. Trending game elements such as interactive narratives or immersive visual aesthetics have been rarely explored in HRI studies, whereas finding game designers with experience in designing games with social robots is challenging. We hope the convergence of games and social robots can bring more taxonomies in the future that collect some of our ideas and provide some other elements that allow researchers and designers to simplify the very complex process of creating engaging multiplayer games with robots. Furthermore, although the Robo Ludens taxonomy encompasses our efforts towards proving a simple and comprehensive categorization of specific characteristics that combine both embodied robots and games, it is worth mentioning that the categories in each domain are not mutually exclusive. For instance, robots can be anthropomorphic and artistic simultaneously, in the same way a game can combine the guessing and imitation mechanics to provide a more rich and playful experience.

Despite the limitations listed above, we truly believe it is unlikely that additional studies that were not considered for one reason or another in the present review would have changed the main insights or substantially modified the Robo Ludens taxonomy.

As future directions for this research, we hope novel research in the field can be more conscious of the existing literature [62] and methods that can aid the field to produce genuinely enjoyable and engaging experiences using multiplayer games and social robots. The inclusion of social robots in daily life activities and their acceptance in different scenarios (e.g., schools, hospitals) may require innovative ways to engage different types of audiences on activities that are meaningful and entertaining. The role of HRI in future gameplay design should be addressed in future studies, allowing a more consistent and integrative conversation on how robots can successfully integrate games that are aligned with their hardware/software capabilities. Reciprocally, the role of games in future HRI studies should explore how to create attractive experiences while allowing robots to have a meaningful and playful role, providing a symbiotic combination to foster entertainment and maximize the value in applied games. Novel game interfaces (e.g., physiological computing [39]) and game mediums (e.g., virtual reality) are very promising fields [51] where HRI can leverage on technological advancements and players' adoption to produce unique game experiences with robots.

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