From social robots to creative humans and back

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Abstract

The research on physically and socially situated artificial agents could complement and enrich computational models of creativity. This paper discusses six perspective lines of inquiry at the intersection of creativity and social robotics. It provides a description of ways in which the field of social robotics may influence (and be influenced by) creativity research in psychology and speculates how human-machine co-creation will affect the notions of both human and artificial creativity. By discussing potential research areas, the authors hope to outline an agenda for future collaboration between creativity scholars in psychology, social robotics, and computer science.

Introduction

The field of Human-Robot Interaction (HRI) provides a fertile environment for interdisciplinary dialogue and reciprocal exchange of results, perspectives, methodologies, and scientific language. This is an ideal context to tackle the problem of human and artificial creativity and study how creative outcomes arise from the interaction between human actors and their social and techno-material environment.

Saunders et al. (2010) and Gemeinboeck and Saunders (2013, 2010) were among the first to recognize the potential of HRI to investigate the enacted and embodied nature of creativity. Beyond the opportunities to interact and improvise with a new kind of creative system, the authors addressed the role of shared physical and social space for the transmission of cultural and tacit human knowledge to robotic agents. Fitzgerald, Goel, and Thomaz (2017) further explored the notions of embodied creativity and human-robot co-creativity in tool-rich human environments and pointed to the challenges and opportunities that physical situatedness of robotic agents poses for computational creativity research. After reviewing recent work related to artistic applications of social robots, Lubart et al. (2021) concluded that, in contrast to 'disembodied' computational models of creativity, physically embodied and socially situated artificial agents, i.e., social robots, afford real-time action and co-creation with humans. The authors argued that social robots represent a potentially efficient ecologically-informed instrument to design, support, and extend human creative thought and action, thus complementing computational creativity research. Figure 1 depicts the *process* of Human-Robot co-creation as the inter-action between human (*person*), robot, and their socio-technical environment (*press*), leading to the emergence of novel and useful *products*.

This article provides an overview of the interplay between social robots and creativity research and outlines possible lines of inquiry at the intersection of these fields. Six perspective research directions are identified: 1) development of methodologies for studying human-robot interaction and co-creation; 2) investigation of human-robot teaming and co-creativity in multiple professional contexts; 3) evaluation of robot's and human-robotic system's creative capabilities and outcomes; 4) development of educational applications of social robots to enhance human creativity; 5) artistic applications of social robots; 6) the use of social robots to emulate the human creative process.

Our intention is twofold. First, we reflect on the current state of research in the field of human-robot interaction and propose possible research directions across disciplinary boundaries. Second, we aim at pointing to the current challenges of existing studies and suggest possible solutions.

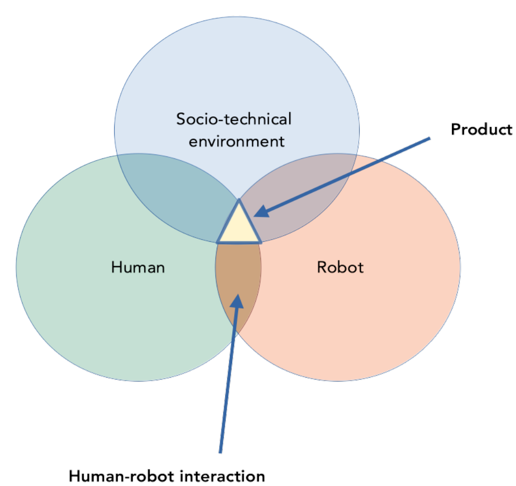

Figure 1: Human-robot co-creation embracing 4 P perspectives on creativity: Person, Process, Press, and Product (Jordanous 2016; Rhodes 1961)

Six lines of research at the intersection of creativity and robotics

A recent review by Guckelsberger et al. (2021) drew attention to the importance of embodiment for computational creativity research and a deeper understanding of human creativity. The authors highlighted the relevance of the 4E Cognition paradigm (Newen, Bruin, and Gallagher 2018; Malinin 2019) for creativity research and called for the embodied computational creativity (CC) research programme. Drawing on this in-depth analysis of embodied CC and recent research in social robotics and cognitive science, below we discuss six perspective lines of inquiry at the intersection of robotics and creativity.

Development of methodologies for studying human-robot interaction and co-creation

As recently noted by Onnasch and Roesler (2021), an increasing variability of existing robots' capabilities and interaction scenarios limits possibilities of comparison and generalization of findings in HRI research. To address this challenge, the authors have proposed a detailed taxonomy to structure and analyse human-robot interaction. Their framework provides three category clusters, such as robot characteristics (e.g., morphology, level of autonomy, task specification), interaction contexts (e.g., field of application, settings), and team classification (team composition, human role, etc). While acknowledging the heuristic value and graphical character of the proposed taxonomy, we suggest that the HRI field may also profit from the adoption of existing methodologies and psychological frameworks to structure different HRI scenarios. Specifically, we see great potential for the application of activity theory initially outlined by Vygotsky (1987) and further developed by Leont'ev (1978), Engeström (1987b), and Kaptelinin and Nardi (2006) as a theoretical lens to formalize the interaction between artificial and human actors.

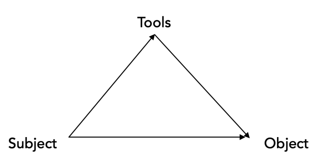

Figure 2: Activity system and two major principles of the activity theory: the tool-mediated character of human activity and its orientation towards an object/outcome.

One of the possible units of analysis in activity theory is an activity system composed of three basic components: subject, tools, and object (outcome) of the activity[1] (fig. 2). Nardi (1996) discussed the resemblance of basic premises of activity theory with theories of situated actions (Suchman 1987) and distributed cognition (Hollan, Hutchins, and Kirsh 2000). Indeed, activity theory is in line with contemporary views of embodied and situated cognition, which consider tools as an organic element of extended cognitive systems (Favela et al. 2021). Engeström (2001; 1987a) also proposed relevant conceptual tools for understanding social action, depicting collaboration as a network of two (or more) interacting activity systems.

Activity level	Question	Description	Example
Activity	Why?	Determined by motives	1a. Building a house; 1b. Completing a software project
Actions	What?	Determined by goals	2a. Laying the foundations; 2b. Programming a module
Operations	How?	Determined by conditions	3a. Using a hammer - grasping, striking; 3b. Using operating system commands

Table 1: Hierarchical structure of activity. Based on Kuutti (1996)

Activity theory considers human behaviour at different levels of abstraction by specifying three possible levels of analysis, ascending from motor operations to complex activities (table 1). Notably, these three levels could be aligned with the three-stratum structure of affordances, proposed under the term *means-end hierarchy* by Vicente and Rasmussen and later elaborated by Wagman, Cialdella, and Stoffregen (2019). Vicente and Rasmussen (1990) suggested that a hierarchically organized set of affordances may be seen as a 'functional landscape' (p.223) through which agents navigate while accomplishing a task.

The concept of affordances has received increased importance in the context of collaborative human-robot activities (Chu and Thomaz 2016; Koppula and Saxena 2015) and creativity research (Kimmel and Hristova 2021; Malinin 2019; Glăveanu 2013). In terms of activity theory, creativity could be re-described as a journey of the actor in interaction with socio-cultural means and tools through a hierarchically organized landscape of affordances towards the production of new and useful artifacts[2].

Advances in the HRI field allow to further develop and adjust activity theory to the current technological context. As such, it could be used as a heuristic model to formalize and understand how human and robotic actors plan their actions and cooperate across three activity levels and multiple interaction layers (Kantosalo et al. 2020) towards a common objective—generating creative artifacts. Different human-robot system configurations could be imagined according to an increased level of robot's autonomy.

[1]For a rigorous and extended description of activity theory and other key components of the activity system: community, rules, and division of labor, see Engeström (1987a; 1987b), and Lindblom and Alenljung (2020), Ceha et al. (2021), Huang and Mutlu (2012) for applications of activity theory in HRI.

[2]In activity theory the artifact is not necessarily material, it could be conceptual or behavioural.

Human-robot teaming and co-creativity in multiple professional contexts

The automation and robotization of human jobs have been considered amongst future global threats, leading to unemployment (Frey and Osborne 2013). Although it is evident that robots will increase their presence in workplace contexts and will automate some routine tasks, in contrast to the 'threatening' view, here we consider possibilities of human-technology teaming (Waefler 2021). In the following, we will speculate on how the role of a robot will depend on how much creativity is needed for the job and how different occupations could benefit from the presence of an embodied artificial agent.

At the first level, we place jobs that eventually necessitate some form of creative problem solving or episodic production of novelty. Examples could be teachers, astronauts, lawyers and alike[3]. At this level, the robot could play a role of a tool in supporting human activity (fig. 3).

An artificial agent might use different strategies to increase human performance and extend the horizon of human action possibilities depending on the stage of the creative process (Amabile 1983; Wallas 1926; Bourgeois-Bougrine et al. 2017):

- Problem definition and representation: suggest searching for alternative formulations of the problem, consider different media to represent it, and look for hidden affordances or relevant problem/object properties and attributes.
- Preparation: find and visualise relevant information or inspiring sets, make mind maps, sketches, planning trees.
- Generation and exploration of possible actions: suggest questioning assumptions, find analogies, use mental/physical synthesis (combination of elements) or disassembly (elimination of elements), search for limitations, potential functions and attributes, means-end analysis, switch attention from problem to the environment, switch mode from generation to action. An artificial agent could also visualise ideas and simulate or model possible movements using their own's bodies.
- Solution evaluation and validation: propose to evaluate the solution from different perspectives, make a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, search for alternative actions and strategies, and analyse failures.

As human creativity could be promoted via physical engagement and exploration (Finke, Ward, and Smith 1992; Glăveanu 2012; Suwa, Gero, and Purcell 2000; Schön 1992), robots seem to be a perfect tool that allows humans to alternate and blend thinking and doing. Beyond cognitive support and stimulation, a robot would provide emotional support and stimulate human motivation due to physical presence—an aspect that has become increasingly important during the COVID crisis. One could envisage that a cup of coffee, a hug (or a kiss using the Kissenger machine (Cheok and Zhang 2020)), or verbal encouragement would be beneficial for the creative process. Another useful function of such an agent-for-every-day-problem-solving could be its ability to keep track of human problem-solving efforts and possibility to retain and analyse successful methods and solutions.

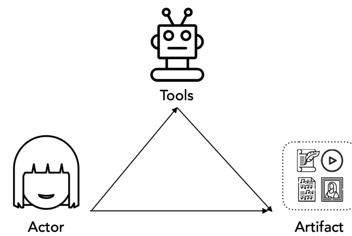

Figure 3: Robot as a tool supporting human creative activity. Adapted from Lubart et al. (2021)

At the second level, we place professions in which the creation of new and valuable artifacts is a necessary part of a job (Koehorst et al. 2019). Professional chefs, art directors, copywriters, and scientists fall into this category. If in the previous scenario, the role of a robot was to inform and stimulate a human actor, this level is marked by an increasing degree of robotic engagement in the human creative process. Beyond the capacities outlined above, a robot is engaged in solution-generation or execution of specific actions and operations set by a human within his or her creative activity. By generating plans and hypotheses and automating human operations, artificial agents would vastly expand the scope and variety of actions available to human actors.

Finally, the third level would be marked by full human-robot teaming, where two activity systems–human and robotic–cooperate in order to achieve a common objective (fig. 4). In the process, they coordinate their activities and synergistically contribute to the production of a novel and valuable artifact. This new type of technologically augmented human creativity (which we call Tech-C) will be paralleled with the emergence of new types of jobs based on mutual inspiration, joint exploration, and co-creation between humans and machines. These new jobs which neither humans nor robots could perform alone should be governed by legal and ethical rules to be developed.

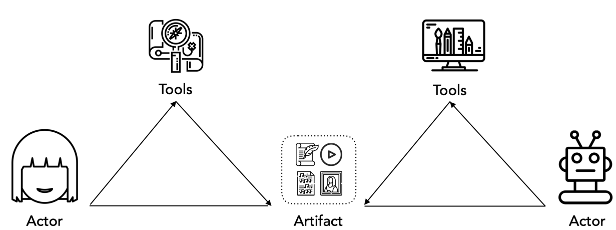

Figure 4: Human-robot co-creation as cooperation of two activity systems. Adapted from Lubart et al. (2021).

[3]We acknowledge that even within these professions the degree of creative intensity could vary and sometimes reach the Pro-C level (Kaufman and Beghetto 2009).

Evaluation of robotic, and human-robotic systems' creative capabilities and outcomes

Increasing human-robotic co-creativity in occupational settings will raise demand for the assessment of creative potentials and evolving creative capacities of robotic and human-robot systems. Developing common metrics to measure robotic capabilities and human-robot interaction is necessary in order to inform future education requirements, anticipate future changes in skill demand (OECD 2021), and improve the performance of human-robot teams (Steinfeld et al. 2006). In this regard, we expect an increasing application of existing human tests and devices as a basis for such assessment.

Not all existing tests would be suitable, however, as many of them are constructed given predominant views of creativity as an essentially 'disembodied phenomenon' that happens mostly in a human mind. Our formalization of creativity as an activity stresses the role of perception and action, as well as symbolic and physical tools for the development of new and useful products. Therefore, below we present examples of possible tests that could be relevant for robotic creativity and human-robot co-creativity assessment accounting for robots' physical embodiment.

- Torrance Thinking Creatively in Action and Movement test (Torrance 1981). This embodied analogue of the Alternative Uses Task (Guilford 1967) would ask a robot to come up and demonstrate multiple ways to do the action (e.g., put a cup in a bin). Initially developed for children starting from 3 years old this test would evaluate the robot's capacity to choose and compose a broad variety of actions to fulfil the same goal. Sufficient behavioural variation along with objects exploration might be key components necessary for innovation and solving new problems in the wild, arguably by increasing the opportunity for learning object affordances and physical properties (Griffin and Guez 2014). This test could be used as inspiration for developing other practical challenges to measure human-robot co-creation.
- Construction using Lego blocks (inspired by Ortiz Jr 2016). A robot would be asked to construct a house using Lego blocks and progressively add new integrated structures such as a garage or a garden. The same task should be completed in multiple possible ways. Collaborative creations could be evaluated via the construction by taking turns with humans.
- Escape-room challenge (inspired by the study by Law, Kasenberg, and Scheutz 2020). A human participant is closed in the room, where the key is out of his/her reach. A social robot capable of moving and understanding human commands is present in the room. The two possible ways to get the key are to use the robot either as a physical tool or a partner to solve the task.

A successful resolution of the proposed challenges involves not only continuous generation of hypotheses and plans but a great extent of exploration of the task's action space. In each case, beyond existing knowledge, the solution depends on the sensorimotor component and the ability to notice and make use of new visuospatial features relevant to the task. These experimental situations testing the actor's behavioral flexibility and ability to improvise solutions with limited available resources have been formalized as MacGyver planning problems (Sarathy and Scheutz 2018) in robotics.

Among other existing tools potentially useful for the evaluation of joint human-robot creation is the Consensual Assessment Technique (Amabile 1982). The technique could be applied for assessing creative artifacts and the gain in the creative output between conditions of human-only creation and creation with a robot[4].

Development of educational applications of social robots to enhance human creativity

An increasing presence of social robots in educational contexts is an established trend (Belpaeme et al. 2018a; Mubin et al. 2013). Studies investigate the educational effectiveness of social robots as tutors (Belpaeme et al. 2018b; Movellan et al. 2009), peers (Kanda et al. 2004; Zaga et al. 2015), and novices (Chase et al. 2009; Tanaka, Cicourel, and Movellan 2007).

In comparison to virtual agents and computer-based tools, physically present systems have numerous advantages when it comes to learning (see Kim and Tscholl 2021, also Li 2015 for review). We also propose that embodied agents support students' situated cognition (Wilson 2002) and learning (Wilson 1993). Situated cognition is coupled with the properties and affordances of settings in which learning takes place and uses these elements to reduce the cognitive workload. Thus, physically present robots have the potential to support such crucial components of scientific discovery as learning by doing, experimentation, observation, and data-driven inferences (see Zimmerman 2007 and Klahr, Fay, and Dunbar 1993 for the description of these components). Active interaction with the environment and hands-on activities, where reasoning and action go in parallel, may allow students to search for evidence not only in the *hypothesis space* of underlying principles but also in the *experiment space* of perceptual cues and patterns. According to Friston et al. (2017) , exploratory behaviour and active sampling of the world often entail unexpected discoveries and may trigger updating learners' explanatory models.

It seems likely that the potential of this technology would expand beyond learning core subjects such as mathematics, reading and science literacy to the development of transversal skills, e.g., critical thinking, creative problem solving, and collaboration. Given the expected increase of robots' participation in occupational fields, early familiarisation with new technology would enable its better acceptance and more fluent and effective human-robot collaboration in the future.

Several recent studies explored the possible benefits of social robots to facilitate creativity in children (Park et al. 2017; Alves-Oliveira et al. 2020; Ali et al. 2021) and adults (Kahn et al. 2016; Alves-Oliveira et al. 2019). In

[4]For further discussion of creativity evaluation in computational co-creative systems see Karimi et al. (2018).

terms of the activity framework, these interventions fall into the application of social robots as a tool to enhance human creative activity. In addition to possible strategies to facilitate the human creative process as outlined in the section devoted to HRI in professional contexts, we expect that social robots could be particularly valuable in the promotion of children's exploration, play, and curiosity, preparing youngsters to adapt to unforeseen circumstances.

Despite its promising potential, this line of research has its pitfalls. Using semi-autonomous or fully tele-operated procedures to enhance creativity with social robots raises the question of whether an eventual effect should be attributed to the robot or human operator. Given this validity issue, interpretation and generalisation of results should be made with caution.

Amplification of artistic applications of social robots

In contrast to the use of social robots as instruments for enhancing the human creative process, researchers started to explore the application of robots as actors participating in creative activity and contributing to the emergence of creative products (Gomez Cubero et al. 2021; Paré 2012; Bretan and Weinberg 2016; Pan, Kim, and Suzuki 2010). We expect that in the next 5 years we will see multiple ways in which the interplay of art and engineering will enrich human artistic culture. Robotic and human actors performing on the theatre stage, human-robot musical bands, and collaborative drawing may open up new forms of art, creating new entry points into robotics and art for children and adults.

Existing examples of making art with robots illustrate moment-to-moment contingency, participatory, and improvisational nature of the creative process. Unfolding through human and robot engagement in shared action, collaborative performance shapes plans and a common vision of the final product. The artistic creative process that arises from human-robot interaction thus represents thus a collaborative dialogic inquiry between participants of the creative process—human artists, machines, materials, and mediating artifacts (Dahlstedt 2012; Ingold 2010). Such physically situated and distributed cognitive systems that coactively exploit and explore affordances and constraints of their surroundings operationalise creative cognition as *creative thinging* (Malafouris 2014), i.e., thinking with and through materials and things.

Human-robot artistic creations integrating and synthetising motion, light, and sound will definitely pose questions of authorship of 'humbot' artifacts. Regardless of whether a social robot could be deemed creative itself and be attributed authorship for its own creation, it is simply a fact that this type of technology will demand humans to be more spontaneous and inventive. Performing with robots which depend on sensory input means that no single linear scenario would be possible. Instead, humans would have to improvise on the fly, imagine multiple alternative paths, and ultimately, develop a larger repertoire of possible actions. This aspect of social robots has the potential to make human-robot cocreation *per se* an ideal training for the unexpected.

Use of social robots to emulate the human creative process

It comes as no surprise that the outlined research directions will be accompanied by continuous efforts to build agents capable to create like humans. Models of the human creative process have been used as inspiration to design creative behaviour in artificial systems (Augello et al. 2016; Hélie and Sun 2010; Vigorito and Barto 2008). Whereas computational models formalize human creativity as a process of solving abstract problems in the absence of a functional body, robots have to deal with the physical world through their sensors and actuators. Although limited by the so-called *curse of dimensionality* (Kober, Bagnell, and Peters 2013, p. 1242), physically and socially present robots afford new and more ecological operationalizations of the creative process and could thus provide additional insight to computational models of creativity.

Guckelsberger et al. (2021) have proposed that robots' sensorimotor capabilities provide an excellent opportunity to examine how creative cognition may be grounded in perception and action. Inspired by recent research in social robotics, Lubart et al. (2021) also suggested that grounding of robots knowledge in vision, audition and proprioception allows to instantiate Ventura's (2016) highest level of computational creativity, where being an embodied author of its sensations a system creates new artifacts based on its own sensorimotor expertise and 'life experience' (see also Colton and Saunders 2018 and Guckelsberger, Salge, and Colton 2017 for further discussion of authenticity, intentionality, and intrinsic motivation in CC systems).

Recently, research has started to address how social robots could demonstrate human-like inventive behaviour in everyday human scenarios, where resources are scarce, and replacement of missing tools is needed (Antunes et al. 2016; Awaad, Kraetzschmar, and Hertzberg 2015). Proposed cognitive architectures allow us to envision social agents capable to improvise solutions for missing equipment by transferring action affordances (Qin, Brawer, and Scassellati 2021; Agostini et al. 2015), discovering new action opportunities (Nyga et al. 2018), and even creating new tools and affordances (Nair and Chernova 2020).

These applications of social robots demonstrate their potential for everyday, little-c creativity (Kaufman and Beghetto 2009), as measured by the Alternative Uses Task. Ironically, as the exact cognitive mechanisms underlying unusual uses are still unknown (but see Gilhooly et al. 2007 and Matheson and Kenett 2020, 2021), robots could help psychologists to unveil the role of language, visual perception, and motor components in performing creative substitutions. The next stage of robots' developmental progression towards creativity would be the development of heuristics permitting agents to choose and evaluate actions based not only on their utility but also on their prospective novelty. One possible way of doing so might be the elaboration of novelty metrics linked to social norms, conventional affordances, and domain standards. Such heuristics estimating 'deviation from normality' and potential utility would enable robots to predict the effect of their action in terms of a potential surprise and value of the final artifact (see Jacob and Magerko 2018 for some examples of possible heuristics).

Conclusion

This paper has attempted to sketch probable future lines of inquiry by crossing interdisciplinary borders of computational creativity, social robotics, and psychology. Imagining and studying possible futures are important to deal better with uncertainties and anticipate opportunities before they emerge and evolve (Broo 2021). We hope that the present work will further stimulate interdisciplinary research investigating the power of embodied agents in relation to the ecological, embedded, enactive, and extended nature of creative cognition.

For centuries, imagination and creativity have been considered as a divine and mysterious spark in humans. Current technological changes allow us to envision a new technologically-augmented type of creativity, in which the inspirational spark would come from the technology and where boundaries between humans and machines would be blurred. We should not forget, however, about the ironies of automation. From one point of view, robotization and increasing human-robot interaction would be the opportunity for humans to offload information and computational processes, freeing up internal capacity for other cognitive and probably more creative tasks (Ecutti, Chemero, and Lee 2021). From a competing point of view, decreasing the frequency of practice of critical creative operations (like idea generation or knowledge retrieval) and outsourcing them to artificial agents could lead to the loss of human creative capacities (Bainbridge 1983). In this regard, the outlined educational interventions, educational robotics (Gubenko et al. 2021), and artistic applications of robots could become critical for preserving human knowledge, flexibility, and the ability to improvise.

Author contributions

AG, TL and CH conceived the article. AG wrote the manuscript and designed figures. TL and CH revised and commented on the text. All authors approved the submitted version.

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