

Co-Creating with a Robot Facilitator: Robot Expressions Cause Mood Contagion Enhancing Collaboration, Satisfaction, and Performance

Authors	de Rooij,Alwin; van den Broek,Simone; Bouw,Michelle; de Wit,Jan
Published in	International Journal of Social Robotics
DOI	10.1007/s12369-024-01177-3
Publication Date	2024-12
Document Version	publishersversion
Link	https://research.tilburguniversity.edu/en/publications/61b64e36-5852-4544-ad89-4e72dda89833
Citation	de Rooij, A, van den Broek, S, Bouw, M & de Wit, J 2024, 'Co-Creating with a Robot Facilitator : Robot Expressions Cause Mood Contagion Enhancing Collaboration, Satisfaction, and Performance', International Journal of Social Robotics, vol. 16, no. 11, 100501, pp. 2133–2152. https://doi.org/10.1007/s12369-024-01177-3
Download Date	2026-05-17 11:54:00
Rights	<p>General rights</p> <p>Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.</p> <ul style="list-style-type: none"> - Users may download and print one copy of any publication from the public portal for the purpose of private study or research. - You may not further distribute the material or use it for any profit-making activity or commercial gain - You may freely distribute the URL identifying the publication in the public portal" <p>Take down policy</p> <p>If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.</p>



Co-Creating with a Robot Facilitator: Robot Expressions Cause Mood Contagion Enhancing Collaboration, Satisfaction, and Performance

Alwin de Rooij^{1,2} · Simone van den Broek¹ · Michelle Bouw² · Jan de Wit²

Accepted: 20 August 2024
© The Author(s) 2024

Abstract

Social robots can be designed to facilitate co-creation. The impact of mood expressions displayed by human facilitators can elicit similar moods in others, fostering collaboration, process satisfaction, and co-creation performance. However, the extent to which robot mood expressions can influence such group dynamics to the same effect remains an open question. To address this, we conducted an experiment ($N = 110$) in which small groups engaged in a co-creation session facilitated by a social robot that displayed positive, neutral, or negative mood expressions. The results showed that robot mood expressions evoked corresponding mood contagion among human group members. The influence of robot expressions on mood valence significantly enhanced group collaboration and process satisfaction. Additionally, participants' ability to contribute insights during the session and ensure these are represented in session outcomes, an index of co-creation performance, significantly improved when positive robot mood expressions increased mood contagion valence. By establishing the influence of robot mood expressions on mood contagion, group collaboration, process satisfaction, and co-creation performance, we shed light on the potential of social robots for facilitating and enhancing co-creation. Understanding the mechanisms underlying these effects adds to a growing body of work in the field of human-robot interaction and offers valuable insights for developing innovative future robotic systems.

Keywords Co-creation · Facilitation · Group dynamics and performance · Mood contagion · Robot expressions · Social robotics

1 Introduction

Co-Creation, the direct involvement of stakeholders in the research and development cycle of organizations, has emerged as a critical practice in both public and private sec-

tors [1]. By enabling users, clients, and other stakeholders to contribute their insights and perspectives, products and services can be developed that effectively balance the diverse needs, goals, and desires of the stakeholders [2]. Dedicated sessions are commonly organized to facilitate co-creation, during which stakeholders collaboratively define problem statements, generate ideas, and develop solutions [3]. A facilitator leads these sessions by providing instructions and supporting task execution while fostering a collaborative climate where stakeholders can contribute their insights and perspectives to the group process and see these represented in session outcomes [4, 5]. Facilitation, however, requires expert knowledge and skill that can be hard to come by [6]. Social robot facilitation might therefore empower organizations with access to the benefits of co-creation in situations where human facilitators require assistance or are unavailable [7, 8].

Social robots are embodied machines designed to socially interact with humans through verbal and non-verbal communication channels, including speech, facial expressions,

✉ Alwin de Rooij
alwinderooij@tilburguniversity.edu

Simone van den Broek
sjce.vandenbroek@avans.nl

Michelle Bouw
m.m.m.c.bouw@tilburguniversity.edu

Jan de Wit
j.m.s.dewit@tilburguniversity.edu

¹ Situated Art and Design Research Group, Centre of Applied Research for Art, Design and Technology, Avans University of Applied Sciences, Onderwijsboulevard 256, 5223 DJ 's-Hertogenbosch, The Netherlands

² Department of Communication and Cognition, Tilburg School of Humanities and Digital Sciences, Tilburg University, Warandelaan 2, 5037 AB Tilburg, The Netherlands

and body language [9–11]. Making use of these communication channels, social robots can be designed to provide, e.g., companionship [12], care [13], services [14], and teaching assistance [15]. Recent research suggests that social robots can also be programmed to facilitate co-creation [8, 16]. For example, Geerts and colleagues [8] demonstrated experimentally how brainstorming with a Wizard-of-Oz controlled Nao robot facilitator, yielded comparable levels of productivity, compared to when participants brainstormed with a human facilitator. Despite several reported limitations, preliminary findings also indicate that users generally respond favorably to robots assuming a facilitatory role [17]. These findings allude to the potential of social robot facilitation. A currently understudied aspect of robot facilitation is the potential of robot mood expressions to enhance co-creation.

Moods are enduring emotional states that vary in felt valence (negativity-positivity) and arousal (calm-excitement) levels [18]. Moods are typically not caused by one particular event but rather emerge from a complex interplay of internal and external factors, including thoughts, physiological states, and environmental circumstances. Perceiving another person's mood can impact one's own accordingly, e.g., through subconscious mimicry of mood expressions produced by others [19]. We refer to this as mood contagion [20]. Hence, mood contagion valence and arousal refer to the transfer of one person's expressed positivity or negativity, and energy as indicated by a range from calm to excited feelings, to another. Moods also function as transient dispositions that influence how a person perceives, thinks, and acts [18, 21]. During group work, positive moods, compared to neutral or negative moods, promote greater group collaboration and process satisfaction [22, 23]. Similarly, positive mood expressions by a facilitator can also promote co-creative performance. That is, such moods may promote a climate where stakeholders feel they can freely contribute their insights and perspectives, cf. [5]. The moods expressed by a facilitator can therefore shape how co-creation sessions unfold.

Whether the mood expressions by a social robot facilitator also influence mood contagion and subsequently group collaboration, process satisfaction, and co-creative performance, remains an open scientific and practical question. Therefore, the following research question (RQ) will be explored:

RQ: Do robot mood expressions cause mood contagion and subsequently influence group collaboration, process satisfaction, and co-creative performance?

In what follows, the rationale introduced above will be unpacked in more detail. We then present the method and results of an experiment ($N = 110$), where small groups of people participated in a co-creation session that was facilitated by a social robot displaying either positive, neutral,

or negative mood expressions. The paper continues with a discussion of the results and the limitations of the study and ends with several proposals for future research aimed at further understanding and realizing the many innovative ways in which social robots can facilitate and enhance co-creation.

1.1 Co-creating with a Robot Facilitator

An emerging body of work suggests that social robots can be programmed to support co-creation. For example, [8] conducted an experiment investigating how the embodiment of a facilitator influences the degree to which stakeholders feel apprehensive about sharing their insights, and how this subsequently affects productivity. While their initial reasoning was that generating insights with a Nao robot facilitator, compared to a human facilitator, would reduce apprehension due to the toy-like appearance of the robot, their findings suggested no significant differences. The participants were similarly productive when the session was facilitated by the robot and by the human facilitator. Relatedly, [16] investigated whether the voice characteristics of a robot facilitator could be used to support group productivity and creativity during a co-creation session. When the EZ robot facilitated a free association and product development task with a charismatic voice, compared to a non-charismatic voice, participants were more productive and creative. This, however, appeared to come at the cost of group resilience. These findings underline both the preliminary status and the potential of robot facilitation.

Compared to other technologies, social robots may be particularly suitable for taking on a facilitatory role due to their ability to socially interact with users through natural communication channels and within a situated context. For example, [24] demonstrated how facilitating the design of a Zen garden with a teleoperated Robovie robot, compared to facilitation with a PowerPoint presentation, enhanced the participants' productivity. In a more collaborative setting, [25] demonstrated that interacting with the social robot Jibo during a drawing task elicited higher productivity, originality, and enjoyment when compared to facilitation through a tablet PC. Other studies from the field of child-robot interaction show how various interactions that are commonly displayed by a co-creation facilitator positively influence various indices of productivity and creativity, including positive reinforcement [26], implementing creativity techniques [27], and suggesting creative ideas [25, 28]. Though note that some contrasting findings have also been observed [29, 30].

Others have explored the perception of social robots taking on a facilitatory role. For example, [17] found that the Nao robot, when it facilitated a collaborative planning task, elicited a generally favorable attitude toward the robot. Previous experience with the Nao robot slightly reduced this positive attitude, likely due to the absence of a novelty effect,

whereas it also increased group performance. Relatedly, [31] explored the perceived benefits and drawbacks of deploying the Nao robot in a facilitator role during problem definition, idea generation, and solution development activities in a design process. Frequently reported benefits included the robot's efficiency, accuracy, and consistency, as well as its friendly and non-judgmental appearance and behavior. However, the participants also reported a range of limitations, including limited communication skills, inability to effectively build on details of the group's process, and violation of social norms. Overall, these initial findings suggest that robot facilitation is viewed generally favorably by users. Optimistically, current developments in natural language processing and generation suggest that some of the limitations of robot facilitation can be addressed in the short term [32].

Together, these studies affirm both the preliminary status and the potential of social robots taking on a facilitatory role. Within this space of possibilities, several open questions emerge regarding the application of robot facilitation in supporting group dynamics and performance during co-creation. Crucially, this calls for research that goes beyond the more general measures of productivity and creativity seen in the research presented above. Prior research suggests that there exists untapped potential in harnessing the natural communication capabilities of social robots, particularly by designing robot mood expressions, to positively influence how co-creation sessions unfold.

1.2 Mood Contagion and Co-creation

Mood contagion is a social phenomenon where perceiving one person's expressions influences one's own mood accordingly [20, 33]. As this other person also expresses their mood, a convergence of moods and associated behaviors can occur within groups [34, 35]. One underlying cause of mood contagion is the subconscious mimicry of others' expressions [19]. Mimicry, in turn, triggers embodied feedback that, when associated with specific moods, invokes a regulatory mechanism that promotes congruence between the perceived mood expressed by another person and one's own. Moreover, individuals learn how to respond with appropriate moods and emotions to their interpretation of someone else's mood expressions. Over time, and through repetition, such stimulus–response relationships become ingrained, such that perceiving a mood expression's valence and arousal automatically triggers experiencing associated levels of valence and arousal [19, 36]. While this may not always lead to mood convergence [34], various social motivators promote aligning one's mood with the mood of another person, including establishing connection and affiliation [37], empathy [38], and conformity to social norms [39].

Moods serve as transient dispositions that exert influence over individuals' perceptions, cognition, and behaviors [18,

21]. When individuals experience positively valenced moods, for example, they tend to direct their attention toward the positive aspects of their internal and external environment. Positive moods signal to the self that the environment is benign, whereas negative moods signal the environment is problematic. In the context of group work, positive and negative moods among human group members guide their attention toward the positive and negative aspects of the group's functioning [40], thereby influencing the way they think about and act within the group [34]. For instance, [22] demonstrated that moods displayed by a group member resulted in mood contagion, and its effects on mood contagion valence subsequently enhanced collaboration within the group. The effects of mood contagion have been consistently replicated across a diverse range of group processes and outcomes [34], including group collaboration [41], performance [42], and overall process satisfaction [23].

When instructing or supporting task execution, facilitator mood expressions can evoke mood contagion and associated behaviors, shaping how a co-creation session unfolds. Successful co-creation requires a facilitator who cultivates a collaborative environment, enabling diverse stakeholders to freely share insights and work together to define problems, generate ideas, and develop solutions [3]. Moreover, facilitators must empower stakeholders to contribute their unique perspectives and ensure their contributions are represented in session outcomes [2, 5]. This lies at the heart of co-creative performance, showcasing the group's ability to extract diverse stakeholder needs, goals, and desires, and integrate them into session outcomes. Considering the previous work discussed above, we conjecture that positively valenced expressions by a facilitator, compared to neutral or negatively valenced expressions, influence mood contagion valence accordingly among stakeholders engaged in co-creation [19, 36]. Mood contagion valence, subsequently, positively influences group collaboration [22, 34], and co-creative performance [5]. Moreover, since positive moods significantly influence an individual's perception of group functioning [40], they are likely to enhance overall satisfaction with the group process [23].

The aforementioned conjectures regarding the connections of facilitator mood expressions and mood contagion, with group collaboration, process satisfaction, and co-creation performance, are based on established psychological research conducted primarily among human beings. However, it remains an open scientific and practical question whether social robots can be designed to express their moods such that these achieve similar outcomes among human groups.

1.3 The Present Study

Answering this open question calls for further inquiry into how unique aspects of social robots might affect the elicitation of mood contagion and subsequent effects on group collaboration, process satisfaction, and co-creation performance.

Human beings express their moods through relatively distinct paralinguistic speech features [43], facial expressions [44], and body language [45]. Social robots are designed to interact socially with people through natural communication channels, which are made possible by digital and mechanical production mechanisms for speech, facial expressions, and body language. Consequently, these also provide a platform for designing and displaying mood expressions [46], albeit often with limited degrees of freedom [47]. The accuracy of human perceptions of social robot mood expressions, when compared to interpreting the expressions of other humans, however, seems markedly low. A recent systematic review by Stock-Homburg [48] suggests that the average recognition rate of robot facial expressions, for example, is in the range of 39% to 71%. In comparison, the findings by Dores and colleagues [49] suggest that the average recognition rate of human facial expressions is in the range of 56% to 93%. The modest accuracy of human perceptions of robot mood expressions raises questions about the efficacy of social robots in eliciting mood contagion. Note that in the present study, the user's perceived valence (negativity-positivity) and arousal (calm-excitement) of a robot's behavior are referred to as robot mood valence and arousal, or interchangeably as robot valence and robot arousal.

When robot expressions do not sufficiently convey the paralinguistic, facial expression, and body language features a person normally relies on to correctly interpret the mood expression [48], a tendency to mimic the robot's expressions is less likely to evoke the regulatory mechanisms that underpin mood contagion, cf. [19, 36]. Compounding this issue, we can assume that limited accuracy also reduces the likelihood that learned and automatized relationships between observed mood expressions and associated experienced moods are elicited. Despite these potential limitations, previous studies have shown that positive robot mood expressions increase mood valence in individuals who watch and listen to a robot telling a story [50] or delivering a lecture [51]. Interactions with a robot facilitator, however, are typically limited to specific moments, such as when the robot facilitator provides instructions or supports task execution [8], while the human stakeholders primarily interact with each other [16]. This comparably limited number of interactions restricts the potential influence of robot expressions on mood contagion within the group. Whether and how robot expressions are

perceived is therefore critical for the effective elicitation of mood contagion.

Social robot embodiment might also affect its capacity for eliciting mood contagion due to a robot's perceived identity. Robots are often perceived as something in between technological objects and, perhaps animal-like, animate beings [52], with many also having a toy-like appearance [53]. These perceptions shape people's interactions and relationships with robots [54]. Social motivations, including tendencies to connect and affiliate [37], empathize [38], and conform to social norms [39], play a vital role in eliciting mood contagion. On the one hand, social robots might be limited in those regards due to their perceived non-human identity (e.g., [8]). On the other hand, a large body of work shows that people do empathize with social robots [55] and that these social robots can take on a companionship role effectively, indicating a social motivation to connect and affiliate with them [12]. Given that previous work also suggests a generally favorable attitude toward robots taking on a facilitation role [17, 31], this further affirms the, albeit potentially limited, capacity of robot facilitators to elicit mood contagion. To test the conjectures developed above, the following hypothesis will be tested:

H1: Positive robot mood expressions, compared to neutral and negative expressions, positively influence mood contagion valence in a manner that is conditional upon perceived robot mood valence.

The impact of a robot facilitator's mood expressions on mood contagion valence, on subsequent group collaboration, process satisfaction, and performance during co-creation, points to yet another currently unresolved question. Not all effects observed in human-human interactions can be reliably replicated in the context of human-robot interaction [56]. Verbal statements to promote collaboration made by a MyKeepon robot had no significant effect on children's group dynamics during a rocket-building task [57]. Whereas [58] demonstrated how interventions by an OWI robot in response to negative human behavior during a bomb-defusing task unexpectedly increased, rather than decreased, conflict among human collaborators. Similarly, previous research by [59] indicated that performance-equalizing statements, which typically foster group cohesion among humans, had the opposite effect when communicated by a social robot. Nonetheless, there is limited knowledge regarding whether known effects of human mood expressions on the relationship of mood contagion valence with group collaboration [41], process satisfaction [23], and performance [42], can be elicited by robotic mood expressions to the same effect. This is within and outside the context of robot facilitation of co-creation. To learn more, the following working hypothesis will therefore be tested:

H2: *The conditional effect of positive robot mood expressions on mood contagion valence via perceived robot mood valence, positively influences group collaboration, process satisfaction, and co-creation performance.*

2 Method

2.1 Design

To test the hypotheses an experiment was conducted with a mixed within-between-subjects design. Groups of 3–5 participants took part in co-creation sessions led by a robot facilitator. While facilitating the session, the robot displayed either positive, neutral, or negative mood expressions. The robot expressions were the between-subjects independent variable. The co-creation session consisted of five different tasks. After each task participants self-reported robot valence and arousal (mediators), mood contagion valence and arousal (mediators), and group collaboration, process satisfaction, and co-creation performance (dependent variables). Manipulation checks were also administered. These repeated measures were intended to support the precision and stability of the effects of the robot expressions across different elements of a co-creation session. The focus of the present study is expressly on the effects at the between-subjects level since no hypotheses were specified at the within-subjects level. Rather, the repeated measurements served to enhance the measurement of the hypothesized effects by repeated testing across different tasks.

2.2 Participants

One hundred ten people participated in the study as part of 29 groups. The average group size was 3.79 ($SD = 0.90$). The participants were recruited using volunteer sampling from the human subjects pool of Tilburg University. All participants were students enrolled in a higher education program. The study was approved by the Research Ethics and Data Management Committee of Tilburg University. The sample characteristics are presented in Table 1.

2.3 Co-creation Session

The participants took part in a co-creation session facilitated by the social robot Nao. The primary objective of this session was for stakeholders to collaboratively address student-health-related challenges by developing problem statements, generating ideas, and exploring potential solutions for this timely issue among students. The participants, who were all students, were therefore stakeholders in this particular matter. The session consisted of five tasks that were

Table 1 Sample characteristics

Sample characteristics	Descriptive statistics
<i>Age category</i>	
16–28	100%
29–39	0%
40–50	0%
51–61	0%
62 or older	0%
<i>Gender</i>	
Female	74%
Male	35%
Non-binary	1%
Other	0%
<i>Co-creation experience (1–4)</i>	
Facilitation	$M = 1.68, SD = 0.90$
Participation	$M = 1.95, SD = 0.97$
<i>Pre-study mood state (1–5)</i>	
Valence	$M = 3.69, SD = 0.79$
Arousal	$M = 2.82, SD = 0.99$

Data are means (M), standard deviations (SD), and percentages (%). Scale ranges are reported between parentheses where appropriate

custom-developed by a co-creation professional. The session started with collaborative brainstorming about the topic ‘health’ during which participants individually wrote down their associations with this topic on white A7 cards (Task 1). The participants then collectively categorized their associations on a table based on six dimensions of health: physical, emotional, intellectual, social, spiritual, and environmental health [60] (Task 2). During this process, the participants were encouraged to add additional associations to the existing ones. Using card sorting methods [61], the stakeholders collectively categorized their previously generated associations based on perceived importance in their daily lives (Task 3). This involved further discussion and determining which associations were deemed most relevant to their overall health and well-being. The groups then engaged in discussions to deliberate on why specific aspects of health held particular importance to them individually or as a group (Task 4). Finally, the stakeholders selected five aspects of health as a group, which they believed could and should be improved, and they collaboratively brainstormed potential solutions for improving these selected aspects of health (Task 5). Please refer to Fig. 1 for further setup details and to the Open Science Framework (OSF) page¹ for the materials used during the co-creation session.

¹ <https://osf.io/awb9j>

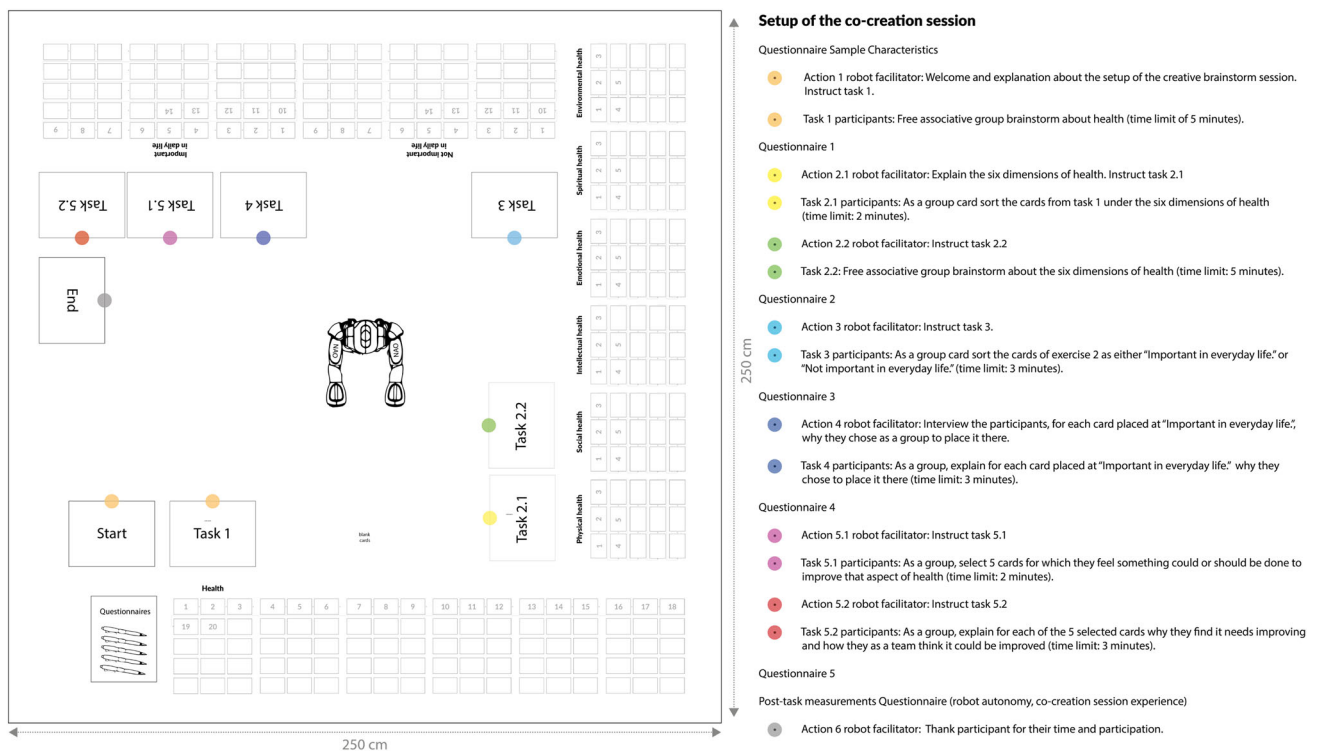


Fig. 1 The co-creation session setup. The social robot facilitator was centrally positioned on a table, and task instructions along with the necessary materials were arranged around it. The robot facilitator facilitated task introduction, time-management, and provided occasional reminders of the instructions throughout the tasks. When transition-

ing to the next task, the robot turned to face the materials associated with the new task. Participants followed the robot from one task to the next. Following the completion of each task, participants filled out questionnaires that captured the mediators, dependent variables, and manipulation checks

2.4 Robot Facilitator

The Nao V6 robot was used with the Choregraphe software to set up a Wizard-of-Oz paradigm [62, 63]. A predefined facilitation protocol developed by a co-creation professional was used by the researcher to trigger the different tasks that formed part of the co-creation session. To ensure the appropriate timing of the robot's actions, the researcher's laptop received a live video stream from a hidden camera placed in the experiment room. Although the researcher had the flexibility to deviate from the protocol or repeat certain steps, such deviations were minimized to maintain consistency across the sessions. The robot assumed multiple facilitatory roles during the session, including introducing tasks, managing time, and delivering brief reminders of the instructions. When transitioning to the next task, the robot physically turned to face the materials associated with that specific task. For tasks with a time limit, a timer automatically prompts the robot's next utterance. However, when the robot needed to wait for a task to be completed, the timing of the robot's actions was controlled by the researcher. The Nao's breathing, eye-blinking, and eye-contact modes were activated to enhance its perceived animacy. On average, the participants somewhat

agreed that the robot operated autonomously ($M = 4.77$, $SD = 1.73$, measured on a scale of 1–7). The complete robot facilitation protocol, as well as the Choregraphe projects for the Wizard-of-Oz paradigm can be found on the OSF page.²

2.5 Robot Mood Expressions

Throughout the co-creation session, the robot either exhibited positive, neutral, or negative expressions. Paralinguistic speech characteristics, facial expressions, and body language (posture and movement) of the robot were manipulated to convey distinct mood expressions. Speech rate, pitch, and Nao speech style settings were used to convey verbal information in a positive, neutral, and negative manner. The verbal interactions with the Nao robot, however, were the same across the experimental conditions. In other words, the only difference between the experimental conditions was in how the robot expressed itself, but not in the content it conveyed. The Nao robot has limited capabilities to display facial expressions. Therefore, we derived an alternative approach inspired by [64], utilizing the color LEDs in the robot's

² <https://osf.io/awb9j>

Table 2 The Nao behavior features and settings used to display negative, neutral, and negative mood expressions. Across the experimental conditions, these robot behavior features differed, while the verbal interactions of the robot with the participants remained the same

Nao behavior features	Positive expressions	Neutral expressions	Negative expressions
Speech rate	65% ^a	85%	60%
Speech pitch	90% ^a	100%	80%
Speech style	'Joyful'	'Neutral'	'Neutral'
Eyes	Alternating LED colors	White LED color	LED off
Head pose	Up	Straight	Down
Hand pose	Open	Semi-open	Closed
Gesture speed	Fast (25 fps)	Medium (15 fps)	Slow (7 fps)
Gesture magnitude	Large	Medium	Small

^a Note that while speech rate and pitch are set lower in the positive expression than in the neutral expression, the robot's speech is still faster and higher pitched because the 'Joyful', compared to the 'Neutral' setting comes, *inter alia*, with increased speech rate and pitch.

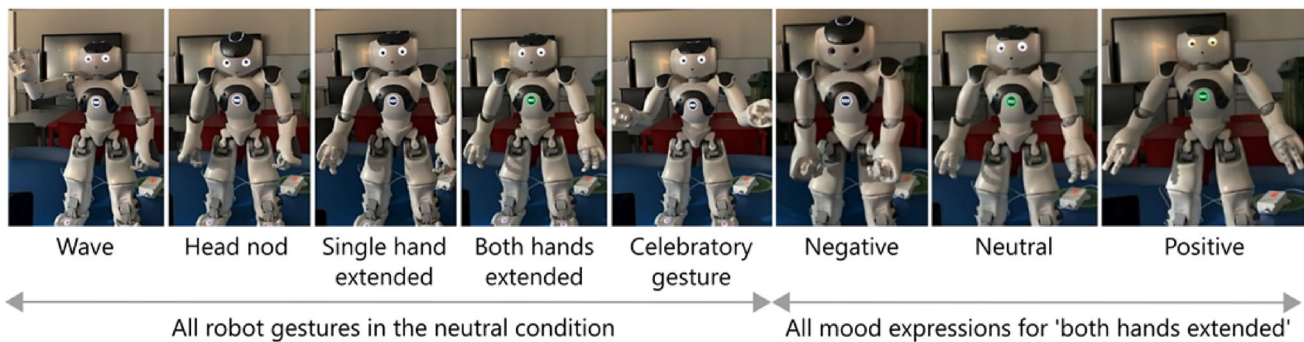


Fig. 2 The neutral version of the robot gestures included in the study: wave, head nod, single hand extended, both hands extended, and celebratory gesture. For the 'both hands extended' gesture, the differences between the negative, neutral, and positive robot expressions are illustrated

eyes as a salient feature in the robot's facial expressions, in combination with different head poses. The robot's verbal interactions were accompanied by one or more of the following types of gestures: hand waving (greeting/goodbye), a head nod, a single hand extended, both hands extended as an invitation, and a celebratory gesture to provide positive feedback. These gestures were designed in the Choregraphe tool by means of so called puppeteering, storing key frames for salient points in the motion and then having the robot interpolate between these key frames. Positive, neutral, and negative variations of these gestures were manually created based on the design principles from a robot mood expression validation study by [65] that in turn were based on observations of human mood expression behavior [66]. See Table 2 and Fig. 2 for details. The robot's mood expressions were iteratively developed and fine-tuned by the research team. The perceived valence of the robot that was measured in the study, described in Sect. 2.6.1, shows that participants attributed the intended types of expressions, and that these differed significantly between the neutral and positive, as well as the positive and negative conditions (see Fig. 4). A Choregraphe project file with all of the designed robot expressions can be found on the OSF page.³

³ creativity_gestures.zip on <https://osf.io/awb9j>

2.6 Measurements

2.6.1 Robot Valence and Arousal

To measure the perceived mood of the robot during the co-creation session, the participants were asked to rate after each task two 5-point semantic differential scales in response to the statement "During the previous task, I perceived the robot to be". These two scales captured robot valence (1 = very negative, 5 = very positive) and robot arousal (1 = very calm, 5 = very excited), cf. [67, 68]. Note that while the hypotheses are largely focused on expression and contagion valence, arousal needs to be taken into account because it is a common confound in research on mood contagion effects [33].

2.6.2 Mood Contagion Valence and Arousal

To measure mood contagion, the participants were asked to rate after each task two 5-point semantic differential scales in response to the statement "During the previous task, I felt:", cf. [20]. That is, contagion valence (1 = very negative, 5 = very positive) and contagion arousal (1 = very calm, 5 = very excited), cf. [67, 68]. Thus, we assume that the portion of felt valence and arousal by the participants that is caused by

variation in perceived robot valence and arousal represents mood contagion.

2.6.3 Group Collaboration, Process Satisfaction, and Co-creation Performance

To capture group collaboration, process satisfaction, and co-creation performance the participants rated 6 items on a 5-point Likert scale after each task (1 = strongly disagree, 5 = strongly agree).

To capture collaboration the participants rated the items “I experienced cooperation with other group members” and “I experienced conflict with other group members”, cf. [22]. The conflict item was reverse-coded so that both items had a polarity indicative of collaboration. Cronbach alpha, however, suggested poor consistency between these two items, $\alpha = 0.42$. Adding the items as separate variables into the statistical analysis, however, would substantially increase the number of model parameters, impeding the statistical validity of the study. We assumed that the cooperation item captured the construct of collaboration more so than the conflict item. Additionally, a visual inspection of the histograms suggested that the conflict item in particular showed flooring effects. At least, more so than the cooperation item. Therefore, the single cooperation item was used in further analyses to represent the collaboration construct.

To capture the participants’ satisfaction with the group process they were asked to rate the items “I felt satisfied with the group process” and “I felt frustrated about the group process”, cf. [69]. The frustration item was reverse coded so that both items had consistent polarity suggesting positive versus negative group affect. Cronbach alpha suggested acceptable consistency between these items, $\alpha = 0.73$. Therefore, the mean of these two items was used in further analyses.

A co-creation session can be considered successful when the facilitator creates a climate where all voices are heard and represented in the outcomes of the session [4, 5]. Critically, participants must feel they can contribute their insights and perspectives to the group, and concretely see that their contributions form part of the co-creation session’s outcomes. To capture this particular index of co-creation performance the participants rated the items “I was able to contribute to the group” and “My contributions to the task were represented in the final outcome of the task”. Cronbach alpha suggested good consistency between these two items, $\alpha = 0.83$. Therefore, the mean of these two items was used in further analyses.

2.6.4 Manipulation Checks

The experimental manipulations might have varied regarding the degree to which the participants were able to understand the robot facilitation due to differences in speech rate and pitch. Relatedly, positive expressions are more salient and

thereby draw more attention [70]. The degree of attention paid to the person, or in our case robot, is a known influence on the efficacy and intensity of mood contagion [71]. To help rule such potential confounds the participants rated the items “I understood the instructions and questions by the robot”, “During the previous task, I paid attention to what the robot said”, and “During the previous task, I paid attention to the robot’s body language (including facial expressions, gesture, posture, movement)” on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The variables these items represent will be referred to as ‘understanding of robot statements’, ‘attention to robot vocalizations’, and ‘attention to robot body language’. At the end of the study, we also checked the degree to which the Wizard-of-Oz setup was successful by asking participants to rate their agreement with the statement “The robot was functioning autonomously” on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

2.6.5 Sample Characteristics

A questionnaire was administered before the co-creation session where the participants filled in their age and gender. The participants were also asked to rate the items “I have facilitated. . .” and “I have participated in creative collaborations before” on a 4-point Likert scale (1 = never, 4 = often) to capture their experience with co-creation, and to rate how they “. . . currently feel” on two 5-point bipolar scales, capturing the valence (1 = very negative, 5 = very positive) and arousal (1 = very calm, 5 = very excited) of their mood state before engaging in the co-creation tasks. Because the sample does not accurately represent the general population, capturing these sample characteristics provides further insight into what population any results might generalize to.

2.6.6 Other Measurements

Participants were asked to answer questions about their feelings of control and to provide feedback on their overall experience of the co-creation session. Specifically, after each task in the session, participants rated the degree to which they believed the robot was in control and the degree to which they felt in control themselves, using a scale from 1 (very not in control) to 5 (very in control). At the end of the study, participants responded to two open-ended questions: “How did you experience the co-creation session?” and “Are there any factors that could improve the overall experience?” These questions and scales were self-generated. While the analysis of these responses is not intended for publication, the data will be used to inform the design of follow-up studies. The complete questionnaires can be found on the project’s OSF page.

Table 3 Descriptive statistics

Robot expressions	Negative	Neutral	Positive
Robot valence	3.49 (0.94)	3.71 (0.74)	4.17 (0.73)
Robot arousal	2.47 (1.10)	2.43 (1.12)	3.76 (1.16)
Contagion valence	3.79 (0.77)	3.79 (0.75)	3.92 (0.78)
Contagion arousal	2.89 (1.08)	2.78 (1.13)	3.10 (1.13)
Collaboration	4.53 (0.62)	4.32 (0.80)	4.43 (0.59)
Process satisfaction	4.51 (0.64)	4.28 (0.80)	4.41 (0.63)
Co-creation performance	4.37 (0.60)	4.30 (0.60)	4.41 (0.60)

The data are the means and standard deviations (between parentheses). The data are based on 501 cases, from 110 participants, from 29 collaborating groups

2.7 Procedure

The study was advertised on the participant pool management system (SONA) page of Tilburg University. When a time slot was selected by 3–5 participants their participation was confirmed. If not, the prospective participants were contacted and asked to select another time slot. Upon arrival, the researcher welcomed the participants and provided them with an information letter and a consent form. After signing informed consent, the group was randomly assigned to one of the experimental conditions. The groups then participated in the co-creation session led by the robot facilitator. Before starting the first task, the participants filled in a questionnaire to capture sample characteristics. After each task of the five tasks, the participants filled in a questionnaire containing the items used to capture robot valence and arousal, mood contagion valence and arousal, and group collaboration, process satisfaction, and co-creation performance. Manipulation checks were administered as part of this questionnaire. The robot was instructing participants when to complete these questionnaires. After finishing the co-creation session, the participants filled in a final questionnaire which contained the Wizard-of-Oz check, were debriefed by the researcher, and received course credit. The study lasted approximately 45 min.

2.8 Data Analysis

Three groups partially completed the experiment due to technical difficulties, which entailed a loss of 37 cases. Additionally, some participants did not fill in all of the questionnaire (e.g., missing a page in the questionnaire). The latter yielded a further loss of 12 cases. Therefore, the dataset used in the analyses consisted of 501 cases, from 110 participants, from 29 groups. The data were analyzed using R 4.20 [72]. To provide insight into the general characteristics of the data the descriptive statistics and correlations were calculated, and the scatter plots and histograms were visualized, using the R package Psych 2.2.5 [73]. To conduct the manipulation checks a multilevel regression analysis was conducted with

the R package Lavaan 0.6.12 [74]. Since we are interested in the between-subjects results, the within-subject level was saturated by covarying all measured variables [74]. These are not reported. At the between-subjects level, the independent variables were the dummy-coded robot expressions. The participants' understanding of the robot's statements and the attention paid to the robot's vocalizations and body language were the dependent variables. According to [75], a reasonable number of cases follows the 10:1 rule where there must be at least 10 cases for each causal path in the model. With 28 causal paths in the largest model in the present study, this would amount to a minimum of 280 cases, which is met by the 501 cases in our current sample. Inspection of the scatter plots and Loess smooths suggested that the relationships in the data sufficiently approximated linearity. There were no signs of multi-collinearity (all $r < 0.700$). The Henze-Zirkler test, conducted with the R package MVN 5.9 [76], suggested a deviation from multivariate normality, $HZ = 1.79$, $p < 0.001$. Therefore, robust test statistics and robust standard errors were used [74]. All robust model fit indices were satisfactory (Table 4, notes) [77].

To conduct the hypothesis tests a multilevel path analysis was conducted with Lavaan 0.6.12 [74]. Again, all variables at the within-subject level were covaried and these results are not reported [74]. At the between-subjects level, the dummy-coded robot expressions were specified as the independent variables. Perceived robot valence and arousal were specified as the first mediator type, and mood contagion valence and arousal were specified as the second mediator type. Robot valence and arousal were not covaried, which reduced the number of model parameters without meaningfully affecting the model fit indices. See Table 4 for the complete model details. The dependent variables were group collaboration, process satisfaction, and co-creation performance. Inspection of the scatter plots and Loess smooths suggested that the relationships in the data sufficiently approximated linearity. No signs of multi-collinearity were found (all $r < 0.700$). Here also, the data deviated from multivariate normality, $HZ = 2.64$, $p < 0.001$ [76], and therefore robust test statistics and

robust standard errors were used [74]. All robust model fit indices were satisfactory (Table 5, notes) [77].

3 Results

3.1 Descriptive Statistics and Correlations

To provide insight into the general characteristics of the data the descriptive statistics are presented in Table 3, and the scatter plots, histograms, and correlations are presented in Fig. 3.

3.2 Manipulation Checks

The results of the manipulation checks⁴ are presented in Table 4. During the co-creation session, the participants generally understood (*intercept* = 4.49, *SE* = 0.081) and paid attention to the robot's vocalizations (*intercept* = 4.45, *SE* = 0.083), but paid relatively less attention to the robot's body language (*intercept* = 3.48, *SE* = 0.176). These results showed no significant difference in the participants' understanding of the robot's statements when the robot displayed positive expressions, compared to neutral expressions, $b = -0.053$, $p = 0.681$, and negative expressions, $b = 0.019$, $p = 0.866$. Relatedly, the results showed no significant difference in the participants' attention to the robot's vocalizations when the robot displayed positive expressions, compared to neutral expressions, $b = -0.063$, $p = 0.681$, and negative expressions, $b = 0.205$, $p = 0.169$. Similarly, the results showed no significant difference in attention paid to the robot's body language when the robot displayed positive expressions, versus neutral expressions, $b = 0.253$, $p = 0.258$, or versus negative expressions, $b = 0.283$, $p = 0.224$. These findings support the internal validity of the study.

⁴ To further support the internal validity of the study we tested whether the participants' moods before the experiment did not differ significantly for the experimental conditions. To this end, a robust multivariate regression analysis was conducted with the dummy coded robot expressions as the independent variables, and mood valence and arousal reported before the co-creation session as the dependent variables. The results showed no significant difference in mood valence before the experiment when comparing participants in the positive robot expression condition, to the neutral expression condition, $b = 0.056$, $p = 0.787$, nor when compared to the negative expression condition, $b = 0.116$, $p = 0.547$. Similarly, the results showed no significant difference in mood arousal before the experiment when comparing participants in the positive robot expression condition, $b = -0.076$, $p = 0.764$, to the neutral expression condition, nor when compared to the negative expression condition, $b = 0.056$, $p = 0.806$.

3.3 Hypothesis Tests

The results of the hypothesis tests are presented in Fig. 4 and Table 5. The results showed a significant positive effect on robot valence when the robot facilitator led the co-creation session while displaying positive mood expressions, compared to neutral expressions, $b = 0.473$, $p < 0.001$, and negative expressions, $b = 0.668$, $p < 0.001$. There was also a significant positive effect on robot arousal when the robot displayed positive expressions, compared to neutral expressions, $b = 1.303$, $p < 0.001$, and negative expressions, $b = 1.291$, $p < 0.001$. These findings suggest that the mood expressions displayed by the robot facilitator were perceived with relative accuracy by the participants. These findings further support the internal validity of the study.

Regarding mood contagion, the results showed a significant positive effect of robot valence on mood contagion valence, $b = 0.485$, $p < 0.001$. The experimental manipulations, however, did not have a direct effect on mood contagion valence. That is, the results showed no significant effects on mood contagion valence when the robot facilitator displayed positive expressions, compared to neutral expressions, $b = -0.099$, $p = 0.454$, and negative expressions, $b = -0.211$, $p = 0.154$. Rather, tests of the indirect effects showed that the effects of positive robot expressions, compared to neutral expressions, $b = 0.229$, $p = 0.011$, and negative expressions, $b = 0.324$, $p = 0.004$, on mood contagion valence, were conditional upon their effect on robot valence. These findings suggest that the mood expressions displayed by a social robot facilitator can influence mood contagion valence in human groups (Table 6).

The results also showed a significant positive effect of robot arousal on mood contagion arousal, $b = 0.543$, $p < 0.001$. Counter to this positive effect, however, were significant negative direct effects of positive robot expressions, compared to neutral expressions, $b = -0.417$, $p = 0.033$, and negative expressions, $b = -0.526$, $p = 0.003$, on mood contagion arousal. Despite this, the tests of the indirect effects showed there existed positive effects of positive robot expressions, compared to neutral expressions, $b = 0.707$, $p < 0.001$, and negative expressions, $b = 0.701$, $p < 0.001$, on mood contagion arousal, that were conditional upon their effect on robot arousal (Table 6). These findings suggest that the mood expressions displayed by a social robot facilitator can also influence mood contagion arousal in human groups.

Regarding group collaboration, process satisfaction, and co-creation performance, the results showed that mood contagion valence had a significant positive effect on group collaboration, $b = 0.452$, $p = 0.003$, process satisfaction, $b = 0.563$, $p = 0.001$, and co-creation performance, $b = 0.328$, $p = 0.015$. Except for a significant negative effect of robot valence on collaboration, $b = -0.241$, $p = 0.028$, no other significant direct effects were found

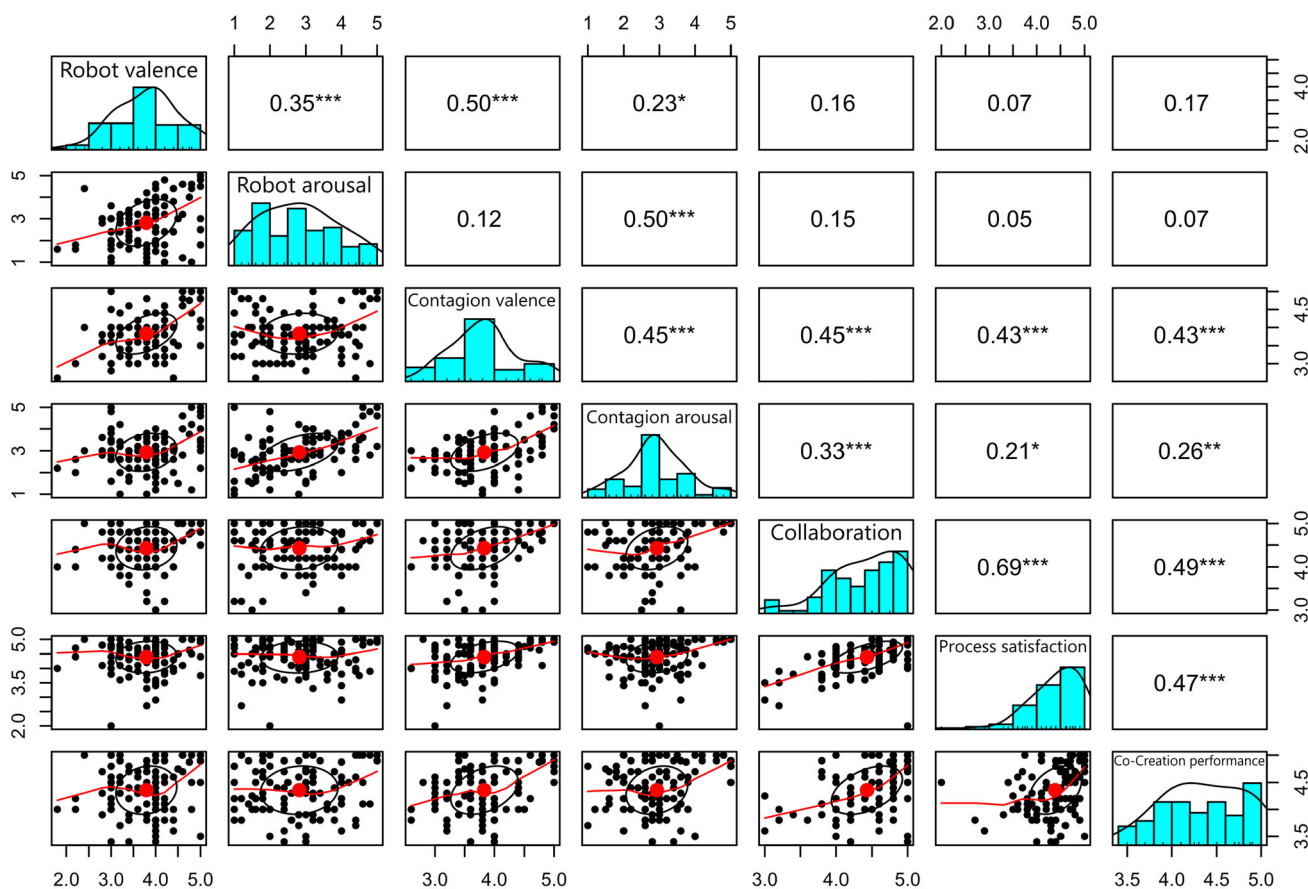


Fig. 3 Scatter plots with Loess smooths (red lines) and correlation ellipses (below the diagonal), histograms with density plots (on the diagonal), and sample size weighted between-subjects Kendall tau-b correlation coefficients. * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$

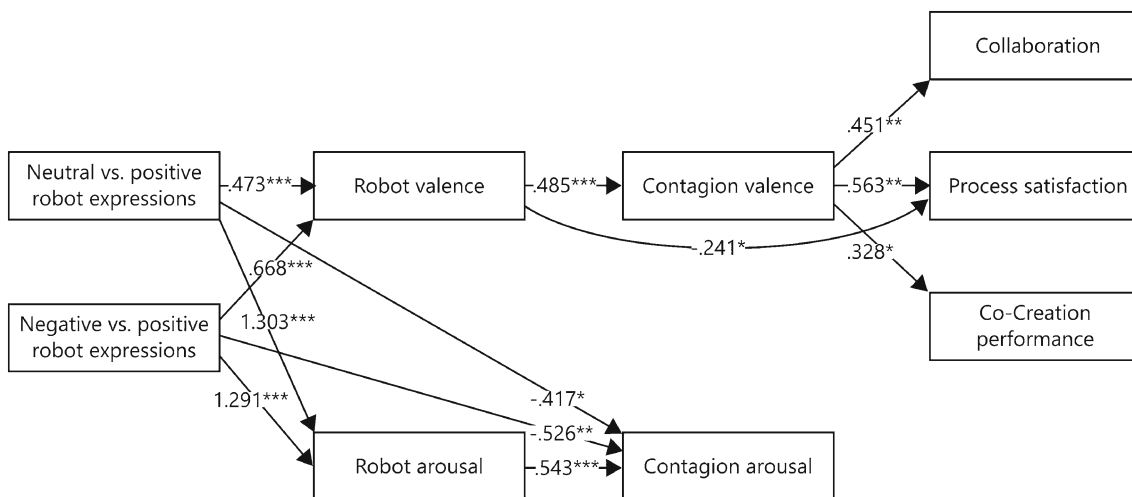


Fig. 4 Overview of the significant results of the multilevel path analysis at the between-subjects level. * $p < 0.050$, ** $p < 0.010$, *** $p < 0.001$

on group collaboration, process satisfaction, and co-creation performance (see Table 5).

The tests of indirect effects, however, showed that when the robot facilitator led the co-creation session while displaying positive robot expressions, compared to neutral

expressions, this positively influenced group collaboration, $b = 0.104$, $p = 0.032$, satisfaction, $b = 0.129$, $p = 0.040$, and co-creation performance, $b = 0.075$, $p = 0.054$, and which effect was conditional upon its effects on robot valence and subsequent mood contagion valence. But note that the

Table 4 Results of the manipulation checks

Model details	<i>b</i>	<i>se</i>	<i>z</i>	<i>p</i>
<i>Regressions</i>				
Understanding robot statements ~				
Neutral versus positive robot expressions	-0.053	0.130	-0.41	0.681
Negative versus positive robot expressions	0.019	0.112	0.17	0.866
Attention to robot vocalizations ~				
Neutral versus positive robot expressions	-0.063	0.117	-0.54	0.588
Negative versus positive robot expressions	0.205	0.149	1.37	0.169
Attention to robot body language ~				
Neutral versus positive robot expressions	0.253	0.224	1.13	0.258
Negative versus positive robot expressions	0.283	0.233	1.22	0.224
<i>Covariances</i>				
Understanding robot statements ~ ~				
Attention to robot vocalizations	0.095	0.030	3.18	0.001
Attention to robot body language	0.050	0.046	1.09	0.275
Attention to robot vocalizations ~ ~				
Attention to robot body language ~	0.291	0.067	4.34	<0.001
<i>Intercepts</i>				
Understanding robot statements	4.49	0.081	55.50	<0.001
Attention to robot vocalizations	4.45	0.083	53.50	<0.001
Attention to robot body language	3.48	0.176	19.72	<0.001
<i>Variances</i>				
Understanding robot statements	0.154	0.073	2.10	0.036
Attention to robot vocalizations	0.268	0.068	3.93	<0.001
Attention to robot body language	0.685	0.109	6.26	<0.001

Note. The data are unstandardized regression coefficients (*b*), robust standard errors (*se*), z-scores (*z*), and p-values (*p*). The presented results are the between-subjects results of the model. Robust model fit indices: Comparative Fit Index = 1.00, Tucker-Lewis Index = 1.00, Root Mean Square Error of Approximation = 0.00, Standardized Root Mean Square Residual (between covariance matrix) = 0.00

indirect effect on co-creation performance was not significant ($p < 0.100$). Complementarily, positive robot expressions, compared to negative expressions, also significantly and positively influenced group collaboration, $b = 0.146$, $p = 0.022$, satisfaction, $b = 0.182$, $p = 0.025$, and co-creation performance, $b = 0.106$, $p = 0.037$, and which effect was conditional upon its effects on robot valence and subsequent mood contagion valence. These findings suggest that the mood expressions of a robot facilitator can positively influence group collaboration, process satisfaction, and co-creation performance, in a manner that is conditional upon the perceived valence of the robot expressions, and its subsequent effect on mood contagion valence in the participants (Table 7).

4 Discussion

The presented study explored whether robot mood expressions cause mood contagion and subsequently enhance group

collaboration, process satisfaction, and co-creative performance.

The results showed that positive robot mood expressions, compared to neutral and negative expressions, positively influence mood contagion valence in a manner that is conditional upon perceived robot valence. Additionally, the results also showed how the positive robot mood expressions displayed by the robot facilitator positively influenced mood contagion arousal, in a manner that is conditional upon perceived robot arousal. These results support hypothesis H1. At first glance, these findings align with previous work suggesting that social robots can elicit mood contagion when telling a story [50] or delivering a lecture [51]. However, the effects of the robot's behavior on mood contagion might be driven more strongly by the expressive features in the robot's vocalizations than its body language. See Table 4 (intercepts). This introduces uncertainty about what aspects of the robot's behavior drive the found effects on mood contagion, and whether this lower attention to body language might alternatively explain the solely indirect effects of the

Table 5 Results of the multilevel path model analysis at the between-subjects level

Model details	<i>b</i>	<i>se</i>	<i>z</i>	<i>p</i>
<i>Regressions</i>				
Robot valence ~				
Neutral versus positive robot expressions	0.473	0.133	3.56	<0.001
Negative versus positive robot expressions	0.668	0.149	4.48	<0.001
Robot arousal ~				
Neutral versus positive robot expressions	1.303	0.228	5.72	<0.001
Negative versus positive robot expressions	1.291	0.207	6.23	<0.001
Contagion valence ~				
Robot valence	0.485	0.096	5.07	<0.001
Neutral versus positive robot expressions	-0.099	0.133	-0.74	0.457
Negative versus positive robot expressions	-0.211	0.148	-1.42	0.155
Contagion arousal ~				
Robot arousal	0.543	0.088	6.20	<0.001
Neutral versus positive robot expressions	-0.417	0.196	-2.13	0.033
Negative versus positive robot expressions	-0.526	0.179	-2.93	0.003
Collaboration ~				
Contagion valence	0.452	0.151	2.99	0.003
Contagion arousal	0.038	0.099	0.38	0.701
Robot valence	-0.082	0.117	-0.70	0.482
Robot arousal	0.074	0.091	0.82	0.415
Neutral versus positive robot expressions	0.025	0.157	0.157	0.875
Negative versus positive robot expressions	0.197	0.153	1.29	0.198
Process satisfaction ~				
Contagion valence	0.563	0.170	3.31	0.001
Contagion arousal	-0.035	0.104	-0.34	0.735
Robot valence	-0.241	0.110	-2.19	0.028
Robot arousal	0.044	0.095	0.47	0.639
Neutral versus positive robot expressions	0.121	0.156	0.77	0.437
Negative versus positive robot expressions	-0.046	0.150	-0.30	0.762
Co-Creation performance ~				
Contagion valence	0.328	0.134	2.44	0.015
Contagion arousal	0.065	0.100	0.65	0.514
Robot valence	-0.049	0.111	-0.44	0.662
Robot arousal	-0.028	0.075	-0.37	0.711
Neutral versus positive robot expressions	0.119	0.121	0.98	0.328
Negative versus positive robot expressions	0.087	0.136	0.64	0.521
<i>Covariances</i>				
Contagion valence ~~				
Contagion arousal	0.143	0.047	3.03	0.002
Collaboration ~~				
Process satisfaction	0.089	0.025	3.48	0.001
Co-Creation performance	0.044	0.019	2.38	0.017
Process satisfaction ~~				
Co-Creation performance	0.049	0.018	2.67	0.007
<i>Intercepts</i>				
Robot valence	4.19	0.098	42.52	<0.001
Robot arousal	3.74	0.161	23.18	<0.001
Contagion valence	1.89	0.423	4.47	<0.001

Table 5 continued

Model details	<i>b</i>	<i>se</i>	<i>z</i>	<i>p</i>
Contagion arousal	1.05	0.350	2.98	0.003
Collaboration	2.61	0.36	7.34	<0.001
Process satisfaction	3.15	0.463	6.79	<0.001
Co-Creation performance	3.25	0.345	9.41	<0.001
<i>Variances</i>				
Robot valence	0.288	0.053	5.39	<0.001
Robot arousal	0.681	0.092	7.41	<0.001
Contagion valence	0.162	0.035	4.59	<0.001
Contagion arousal	0.372	0.104	3.58	<0.001
Collaboration	0.111	0.025	4.47	<0.001
Process satisfaction	0.131	0.028	4.63	<0.001
Co-Creation performance	0.109	0.017	6.27	<0.001

The data are unstandardized regression coefficients (*b*), robust standard errors (*se*), z-scores (*z*), and p-values (*p*). The presented results are the between-subjects results of the model. Robust model fit indices: Comparative Fit Index = 1.00, Tucker-Lewis Index = 0.96, Root Mean Square Error of Approximation = 0.03, Standardized Root Mean Square Residual (between covariance matrix) = 0.04

Table 6 Indirect effects on mood contagion

Paths	<i>b</i>	<i>se</i>	<i>z</i>	<i>p</i>
Neutral versus positive robot expressions → Robot valence → Contagion valence	0.229	0.092	2.55	0.011
Negative versus positive robot expressions → Robot valence → Contagion valence	0.324	0.113	2.87	0.004
Neutral versus positive robot expressions → Robot arousal → Contagion arousal	0.707	0.166	4.26	<0.001
Negative versus positive robot expressions → Robot arousal → Contagion arousal	0.701	0.153	4.57	<0.001

Note. The data are unstandardized regression coefficients (*b*), robust standard errors (*se*), z-scores (*z*), and p-values (*p*)

robot mood expressions on user mood contagion. Furthermore, the findings contribute to the existing body of work on robot-induced mood contagion, that when the robot takes on a facilitatory role during a co-creation session, where the robot only typically interacts during key moments, such as when the robot facilitator provides instructions or supports task execution [8], while the human stakeholders primarily interact with each other [16], robot mood expressions can also be utilized to elicit mood contagion.

The results also showed no significant direct effects of positive robot mood expressions, compared to neutral and negative expressions, on mood contagion valence and arousal. As noted, its effects on mood contagion were conditional upon the mood valence and arousal participants attributed to the robot. This might point to several limitations of social robots, and the Nao robot in particular, for

eliciting mood contagion. Speculatively, this finding can be explained by a relatively frequent misperception of robot expressions. The aforementioned limited number of interactions between the robot facilitator and the stakeholders might decrease the likelihood that stakeholders perceive the robot expressions, if at all, as intended. Compounding this potential issue, the comparably limited expressive capabilities of social robots like the Nao, cf. [47, 48], can further hinder evoking mood contagion [19, 36]. Not perceiving or inaccurately perceiving robot expressions decreases both the likelihood that mimicry evokes the appropriate regulatory mechanisms underlying contagion, and of triggering learned and automatized associations between observed expressions and experiencing corresponding moods.

The results showed furthermore that the conditional effect of positive robot mood expressions on mood contagion

Table 7 Indirect effects on group collaboration, satisfaction, and co-creative performance

Paths	<i>b</i>	<i>se</i>	<i>z</i>	<i>p</i>
Neutral versus positive robot expressions	0.104	0.048	2.15	0.031
→ Robot valence				
→ Contagion valence				
→ Collaboration				
Negative versus positive robot expressions	0.146	0.064	2.29	0.022
→ Robot valence				
→ Contagion valence				
→ Collaboration				
Neutral versus positive robot expressions	0.129	0.063	2.06	0.040
→ Robot valence				
→ Contagion valence				
→ Process satisfaction				
Negative versus positive robot expressions	0.182	0.082	2.23	0.025
→ Robot valence				
→ Contagion valence				
→ Process satisfaction				
Neutral versus positive robot expressions	0.075	0.039	1.93	0.054
→ Robot valence				
→ Contagion valence				
→ Co-Creation performance				
Negative versus positive robot expressions	0.106	0.051	2.09	0.037
→ Robot valence				
→ Contagion valence				
→ Co-Creation performance				

Note. The data are unstandardized regression coefficients (*b*), robust standard errors (*se*), z-scores (*z*), and p-values (*p*)

valence via perceived robot valence, positively influences group collaboration, process satisfaction, and co-creation performance. Whereas the direct effects of positive robot mood expressions on mood contagion arousal did not significantly affect group collaboration, process satisfaction, and co-creation performance. As such, these results support hypothesis H2. Herewith, the present study replicates previous work on humans, but with a robot, suggesting that mood contagion valence influences a wide range of factors related to group dynamics and performance [34], including group collaboration [41], performance (e.g., [42]), and overall process satisfaction (e.g., [23]). The present study adds new evidence to this growing body of work, by showing how robot facilitator mood expressions can be utilized to beneficially shape how a co-creation session unfolds. This includes the novel finding that positive mood expressions can enhance co-creation performance, as measured by the degree to which the stakeholders felt they were able to contribute their insights and perspectives and the degree to which their contributions were represented in session outcomes, cf. [2, 5].

Specifically, these findings also contribute to a growing body of work on the utilization of social robots in a facilitator

role [8, 16]. Previous studies have demonstrated that robot facilitation, in comparison to other technologies, can enhance productivity and creativity [24, 25]. The present study goes beyond these more general measures of co-creation output, and affirms the potential of robot facilitation for supporting and enhancing co-creation, by shaping aspects of group dynamics and performance that are specifically relevant for successful co-creation [2, 5]. Relatedly, previous work also suggested how attempts to replicate findings from psychology about the influence of human interactions on group dynamics and performance often do not replicate or yield unexpected results when delivered by a social robot [57–59]. Robot mood expressions, as implemented in the present study, did replicate such findings consistently. That is, in alignment with previous work on human-human interaction, robot mood expressions elicited mood contagion and subsequently group collaboration [41], process satisfaction [23], and performance [42] to the same effect.

4.1 Limitations and Future Work

Several limitations should be considered when interpreting the results. To start, it appears that robot facilitation and the tasks executed during the co-creation session were generally well-received by the participants, aligning with previous studies such as those by Buchem [17] and Rosenberg-Kima and colleagues [31]. While this generally favorable reception is encouraging, it might have also introduced ceiling effects (Fig. 3, diagonal), reducing the variance in the data. The use of robust standard errors and test statistics only partially addresses the issues introduced by the ceiling effects, and thus, the presence of ceiling effects threatens the statistical validity of the study. Relatedly, the choice to represent collaboration merely with the ‘cooperation’ item does not permit testing consistency and reduces the scope of this measurement, which threatens its construct validity. Another limitation is the reliance on self-report measures rather than behavioral observations, cf. [22]. The use of self-reported data possibly introduces a range of well-documented response biases or inaccuracies, as self-reports often differ from observed behaviors. Relatedly, the use of the words calm and excited in the semantic differential scales that measured robot arousal and mood contagion arousal might have been biased toward positive valence, as some studies suggest that these words are not only associated with low and high arousal levels but also with low positive valence [68]. Lastly, the study employed a Wizard-of-Oz setup, which entails that the robot has no autonomy [32]. This threatens the ecological validity of human-robot interactions tested in this study. For the present study, three variations of the robot’s behavior (i.e., the gestures) were manually developed to portray the three different robot expressions (positive, neutral, negative). To generalize this to other behaviors, including those where the robot is using its body to perform other, task-related actions while conveying a certain mood, a parameterized model could be used to adjust the mood of any behavior in real-time [65, 78].

The presented study can inform several new directions for future research aimed at further understanding and realizing the innovative ways in which social robots can facilitate and enhance co-creation. We propose the following directions as a starting point.

Firstly, we propose that understanding the limitations of robot mood expressions can enhance robot-elicited mood contagion and its effects on group collaboration, process satisfaction, and co-creation performance. One question is whether the effect of robot mood expressions relies on mimicry. An approach to explore this could be to design an experiment where we interfere with the activation of the Zygomaticus major muscle, which is involved in smiling, to determine if positive robot expressions still evoke positive moods to a similar effect, than when the activation of

this muscle is not interfered with, cf. [19, 79]. If mimicry is indeed a core mechanism, further engineering and design work must be undertaken to refine the robot’s expressive capabilities, such that people can more accurately perceive the expressions displayed by the robot [80]. Such studies can be enhanced by developing alternative robotic form factors designed to draw attention more strongly to the robot’s body language. In the present study, this appeared limited as indicated by participants paying more attention to the robot’s vocalizations.

Secondly, another question relates to the influence of perceived robot identity. Mood contagion by the social robot might also be explained by triggering learned associations between mood expressions and corresponding experiences [19, 36], which, so we argued, critically depends on how a robot’s perceived identity elicits a range of social motivations, including a tendency to connect and affiliate [37], empathize [38], and conform to social norms [39]. If perceived robot identity is a driver of robot-evoked mood contagion, further design work can explore what robot form factors and behaviors are critical for eliciting mood contagion via this particular route. It would be interesting to study how the robot’s perceived identity and its effects develop as people interact repeatedly with the robot over time. This would also allow us to identify a potential novelty effect of the robot that may have influenced the perceived robot identity or its perceived contribution to the co-creation process [81, 82].

Thirdly, we argue that to optimize the utilization of robot mood expressions and their potential for enhancing collaboration, process satisfaction, and co-creative performance, iterative experimentation and development within the situated context of use is an essential next step. This requires an alternative to Wizard-of-Oz methods, to start with. In the short term, a solution can be found in recent advances in natural language processing and generation [32], which can be used to enable robot autonomy and address known drawbacks of robot facilitation, such as prototyping autonomous behaviors that build on the input of stakeholders during a co-creation session [31]. Combined with the learnings from our first proposed direction for future research, experimentation with social robot facilitators within their context of use can help to fine-tune social robot form factors and behaviors in a manner that further improves the effectiveness of robot mood expressions for eliciting mood contagion. Such future work can help empower organizations with access to the benefits of co-creation in situations where human facilitators require assistance or are unavailable [8]. Especially with the advent of large language models [32], autonomously operating social robots could play a supporting role in a multitude of real-world co-creation scenarios, including corporate workshops, education, or healthcare settings [7], if carefully implemented [83, 84].

4.2 Conclusion

In conclusion, the presented study demonstrates that positive mood expressions displayed by a robot facilitator, compared to neutral and negative expressions, evoke mood contagion among group members correspondingly, thereby fostering group collaboration and process satisfaction. The results also revealed a noteworthy improvement in participants' perceived ability to contribute insights during the session and ensure their representation in session outcomes, an index of co-creation performance, due to the influence of robot mood expressions on mood contagion valence. In all cases, the effects of robot facilitator expression on mood contagion depended on perceived robot valence, which highlights one of the challenges that utilizing robot facilitators for enhancing co-creation might come with. By establishing the influence of robot mood expressions on mood contagion, and subsequently group collaboration, process satisfaction, and co-creation performance, we shed new light on the potential of social robots for facilitating and enhancing co-creation. Understanding the mechanisms underlying these effects adds to a growing body of work in the field of human-robot interaction, offering valuable insights that can support the development of innovative future robotic systems.

Acknowledgements A work-in-progress study based on a subset of the data used in the present study, was previously presented at the Eleventh International Conference on Human-Agent Interaction (HAI 2023), 4-7 December 2023, Gothenburg, Sweden. The accompanying article was published in their conference proceedings [85].

Data availability Materials are available under a CC-BY-NC license at <https://osf.io/awb9j>. The data will be made available upon request and without hesitation by the corresponding author and can also be used under a CC-BY-NC license.

Declarations

Conflict of interest The authors have no Conflict of interest to declare.

Ethical Approval Ethical approval was obtained from the Research Ethics and Data Management Committee of Tilburg University. Identification code: TSHD_RP305.

Human Participants All human participants signed informed consent before participating in the study.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copy-

right holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Saha V, Goyal P, Jebarajakirthy C (2021) Value co-creation: a review of literature and future research agenda. *J Bus Ind Mark* 37(3):612–628. <https://doi.org/10.1108/JBIM-01-2020-0017>
- Sanders EB-N, Stappers PJ (2008) Co-creation and the new landscapes of design. *CoDesign* 4(1):5–18. <https://doi.org/10.1080/15710880701875068>
- Jones P (2018) Contexts of co-creation: designing with system stakeholders. In: Jones P, Kijima K (eds) *Systemic design: theory, methods, and practice*. Translational systems sciences, pp 3–52. Springer, Tokyo. https://doi.org/10.1007/978-4-431-55639-8_1
- Michalik G (2023). Co-creation. In: Michalik G (ed) *Co-creation mindset: eight steps towards the future of work*. Management for professionals. Springer, Cham, pp 17–34. https://doi.org/10.1007/978-3-031-21191-1_2
- Soto Hormazábal M, Beaulé CI, Alhonsuo M, Miettinen S (2020). Emotions: the invisible aspect of co-creation workshops. In: *Proceedings of the sixth international conference on design creativity (ICDC 2020)*. pp 192–198. <https://doi.org/10.35199/ICDC.2020.24>
- Rill BR, Hämäläinen MM (2018). *The art of co-creation: a guidebook for practitioners*. Springer, Singapore. <https://doi.org/10.1007/978-981-10-8500-0>
- van den Broek S, Sankaran S, de Wit J, de Rooij A (2024) Exploring the supportive role of artificial intelligence in participatory design: a systematic review. In: *Proceedings of the 18th biennial participatory design conference*. PDC '24. Association for Computing Machinery, New York
- Geerts J, de Wit J, de Rooij A (2021) Brainstorming with a social robot facilitator: Better than human facilitation due to reduced evaluation apprehension? *Front Robot AI*. <https://doi.org/10.3389/frobot.2021.657291>
- Bartneck C, Forlizzi J (2004) A design-centred framework for social human-robot interaction. In: *RO-MAN 2004*. 13th IEEE international workshop on robot and human interactive communication. pp 591–594. <https://doi.org/10.1109/ROMAN.2004.1374827>
- Duffy BR (2003) Anthropomorphism and the social robot. *Robot Auton Syst* 42(3–4):177–190. [https://doi.org/10.1016/S0921-8890\(02\)00374-3](https://doi.org/10.1016/S0921-8890(02)00374-3)
- Fong T, Nourbakhsh I, Dautenhahn K (2003) A survey of socially interactive robots. *Robot Auton Syst* 42(3–4):143–166. [https://doi.org/10.1016/S0921-8890\(02\)00372-X](https://doi.org/10.1016/S0921-8890(02)00372-X)
- Ruggiero A, Mahr D, Odekerken-Schröder G, Spina TR, Mele C (2022) Companion robots for well-being: a review and relational framework. In: *Research handbook on services management*. Edward Elgar Publishing, Northampton, pp 309–330
- Broekens J, Heerink M, Rosendal H (2009) Assistive social robots in elderly care: a review. *Gerontechnology* 8(2):94–103. <https://doi.org/10.4017/gt.2009.08.02.002.00>
- Lu VN, Wirtz J, Kunz WH, Paluch S, Gruber T, Martins A, Patterson PG (2020) Service robots, customers and service employees: What can we learn from the academic literature and where are the gaps? *J Serv Theory Pract* 30(3):361–391. <https://doi.org/10.1108/JSTP-04-2019-0088>
- de Haas M, Vogt P, van den Berghe R, Leseman P, Oudgenoeg-Paz O, Willemsen B, de Wit J, Kraemer E (2022) Engagement in longitudinal child-robot language learning interactions: disentangling robot and task engagement. *Int J Child-Comput Interact* 33:100501. <https://doi.org/10.1016/j.ijcci.2022.100501>

16. Fucinato K, Niebuhr O, Nørskov S, Fischer K (2023) Charismatic speech features in robot instructions enhance team creativity. *Front Commun.* <https://doi.org/10.3389/fcomm.2023.1115360>
17. Buchem I (2023) Scaling-up social learning in small groups with robot supported collaborative learning (RSCL): effects of learners' prior experience in the case study of planning poker with the robot Nao. *Appl Sci* 13(7):4106. <https://doi.org/10.3390/app13074106>
18. Martin LL, Clore GL (eds) (2001) *Theories of mood and cognition: a user's guidebook*. Lawrence Erlbaum Associates Publishers, Mahwah
19. Hatfield E, Cacioppo JT, Rapson RL (1993) Emotional contagion. *Curr Dir Psychol Sci* 2(3):96–100. <https://doi.org/10.1111/1467-8721.ep10770953>
20. Neumann R, Strack F (2000) "Mood contagion": the automatic transfer of mood between persons. *J Personal Soc Psychol* 79(2):211–223. <https://doi.org/10.1037/0022-3514.79.2.211>
21. Schwarz N, Clore GL (2003) Mood as information: 20 years later. *Psychol Inq* 14(3–4):296–303. https://doi.org/10.1207/S15327965PLI14034_20
22. Barsade SG (2002) The ripple effect: emotional contagion and its influence on group behavior. *Adm Sci Q* 47(4):644–675. <https://doi.org/10.2307/3094912>
23. Chi N-W, Chung Y-Y, Tsai W-C (2011) How do happy leaders enhance team success? The mediating roles of transformational leadership, group affective tone, and team processes. *J Appl Soc Psychol* 41(6):1421–1454. <https://doi.org/10.1111/j.1559-1816.2011.00767.x>
24. Kahn PH, Kanda T, Ishiguro H, Gill BT, Shen S, Ruckert JH, Gary HE (2016) Human creativity can be facilitated through interacting with a social robot. In: 2016 11th ACM/IEEE international conference on human-robot interaction (HRI). pp 173–180. <https://doi.org/10.1109/HRI.2016.7451749>
25. Ali S, Park HW, Breazeal C (2021) A social robot's influence on children's figural creativity during gameplay. *Int J Child-Comput Interact* 28:100234. <https://doi.org/10.1016/j.ijcci.2020.100234>
26. Elgarf M, Calvo-Barajas N, Alves-Oliveira P, Perugia G, Castellano G, Peters C, Paiva A (2022) "And then what happens?" promoting children's verbal creativity using a robot. In: 2022 17th ACM/IEEE international conference on human-robot interaction (HRI), pp 71–79. <https://doi.org/10.1109/HRI53351.2022.9889408>
27. Alves-Oliveira P, Arriaga P, Nogueira SI, Paiva A (2021) Robotics-based interventions for children's creativity. In: *Proceedings of the 13th conference on creativity and cognition*. Association for Computing Machinery, New York, pp 1–8. <https://doi.org/10.1145/3450741.3465267>
28. Ali S, Moroso T, Breazeal C (2019) Can children learn creativity from a social robot? In: *Proceedings of the 2019 conference on creativity and cognition*. Association for Computing Machinery, New York, pp 359–368. <https://doi.org/10.1145/3325480.3325499>
29. Alves-Oliveira P, Arriaga P, Cronin MA, Paiva A (2020) Creativity encounters between children and robots. In: *Proceedings of the 2020 ACM/IEEE international conference on human-robot interaction*. Association for Computing Machinery, New York, pp 379–388. <https://doi.org/10.1145/3319502.3374817>
30. Elgarf M, Skantze G, Peters C (2021) Once upon a story: Can a creative storyteller robot stimulate creativity in children? In: *Proceedings of the 21st ACM international conference on intelligent virtual agents*. IVA '21. Association for Computing Machinery, New York, pp 60–67. <https://doi.org/10.1145/3472306.3478359>
31. Rosenberg-Kima RB, Koren Y, Gordon G (2020) Robot-supported collaborative learning (RSCL): social robots as teaching assistants for higher education small group facilitation. *Front Robot AI.* <https://doi.org/10.3389/frobt.2019.00148>
32. Vrins A, Pruss E, Ceccato C, Prinsen J, de Rooij A, Alimardani M, de Wit J (2024) Wizard-of-Oz vs. GPT-4: a comparative study of perceived social intelligence in HRI brainstorming. In: *Proceedings of the 2024 ACM/IEEE international conference on human-robot interaction*. <https://doi.org/10.1145/3610978.3640755>
33. Herrando C, Constantinides E (2021) Emotional contagion: a brief overview and future directions. *Front Psychol.* <https://doi.org/10.3389/fpsyg.2021.712606>
34. Barsade SG, Knight AP (2015) Group affect. *Annu Rev Organ Psych Organ Behav* 2(1):21–46. <https://doi.org/10.1146/annurev-orgpsych-032414-111316>
35. van Haeringen ES, Gerritsen C, Hindriks KV (2022) Emotion contagion in agent-based simulations of crowds: a systematic review. *Auton Agent Multi-Agent Syst* 37(1):6. <https://doi.org/10.1007/s10458-022-09589-z>
36. Elfenbein HA (2014) The many faces of emotional contagion: an affective process theory of affective linkage. *Organ Psychol Rev* 4(4):326–362. <https://doi.org/10.1177/2041386614542889>
37. Huntsinger JR, Lun J, Sinclair S, Clore GL (2009) Contagion without contact: anticipatory mood matching in response to affiliative motivation. *Pers Soc Psychol Bull* 35(7):909–922. <https://doi.org/10.1177/0146167209335299>
38. Hatfield E, Rapson RL, Le Y-CL (2009) *Emotional contagion and empathy*. In: *The social neuroscience of empathy*. Social neuroscience. Boston Review, Cambridge, pp 19–30. <https://doi.org/10.7551/mitpress/9780262012973.003.0003>
39. Kimura M, Daibo I, Yogo M (2008) The study of emotional contagion from the perspective of interpersonal relationships. *Soc Behav Personal Int J* 36(1):27–42. <https://doi.org/10.2224/sbp.2008.36.1.27>
40. Homan AC, Van Kleef GA, Sanchez-Burks J (2016) Team members' emotional displays as indicators of team functioning. *Cogn Emot* 30(1):134–149. <https://doi.org/10.1080/02699931.2015.1039494>
41. Lin C-P, He H, Baruch Y, Ashforth BE (2017) The effect of team affective tone on team performance: the roles of team identification and team cooperation. *Hum Resour Manag* 56(6):931–952. <https://doi.org/10.1002/hrm.21810>
42. Volmer J (2012) Catching leaders' mood: contagion effects in teams. *Adm Sci* 2(3):203–220. <https://doi.org/10.3390/admsci2030203>
43. Gideon J, Provost EM, McInnis M (2016) Mood state prediction from speech of varying acoustic quality for individuals with bipolar disorder. In: 2016 IEEE international conference on acoustics, speech and signal processing (ICASSP), pp 2359–2363. <https://doi.org/10.1109/ICASSP.2016.7472099>
44. McClure EB, Pope K, Hoberman AJ, Pine DS, Leibenluft E (2003) Facial expression recognition in adolescents with mood and anxiety disorders. *Am J Psychiatry* 160(6):1172–1174. <https://doi.org/10.1176/appi.ajp.160.6.1172>
45. Kleinsmith A, Bianchi-Berthouze N (2013) Affective body expression perception and recognition: a survey. *IEEE Trans Affect Comput* 4(1):15–33. <https://doi.org/10.1109/T-AFCC.2012.16>
46. Melo CM, Gratch J, Marsella S, Pelachaud C (2023) Social functions of machine emotional expressions. *Proc IEEE* 111(10):1382–1397. <https://doi.org/10.1109/JPROC.2023.3261137>
47. de Rooij A, Broekens J, Lamers MH (2013) Abstract expressions of affect. *Int J Synth Emot (IJSE)* 4(1):1–31. <https://doi.org/10.4018/jse.2013010101>
48. Stock-Homburg R (2022) Survey of emotions in human-robot interactions: perspectives from robotic psychology on 20 years of research. *Int J Soc Robot* 14(2):389–411. <https://doi.org/10.1007/s12369-021-00778-6>
49. Dores AR, Barbosa F, Queirós C, Carvalho IP, Griffiths MD (2020) Recognizing emotions through facial expressions: a largescale experimental study. *Int J Environ Res Public Health* 17(20):7420. <https://doi.org/10.3390/ijerph17207420>
50. Xu J, Broekens J, Hindriks K, Neerinx MA (2015) Effects of a robotic storyteller's moody gestures on storytelling perception. In:

- 2015 international conference on affective computing and intelligent interaction (ACII), pp 449–455. <https://doi.org/10.1109/ACII.2015.7344609>
51. Xu J, Broekens J, Hindriks K, Neerinx MA (2014) Effects of bodily mood expression of a robotic teacher on students. In: 2014 IEEE/RSJ international conference on intelligent robots and systems, pp 2614–2620. <https://doi.org/10.1109/IROS.2014.6942919>
 52. Coeckelbergh M (2011) Humans, animals, and robots: a phenomenological approach to human-robot relations. *Int J Soc Robot* 3(2):197–204. <https://doi.org/10.1007/s12369-010-0075-6>
 53. Scassellati B, Admoni H, Mataric M (2012) Robots for use in autism research. *Annu Rev Biomed Eng* 14(1):275–294. <https://doi.org/10.1146/annurev-bioeng-071811-150036>
 54. Prescott TJ, Robillard JM (2021) Are friends electric? The benefits and risks of human-robot relationships. *iScience* 24(1):101993. <https://doi.org/10.1016/j.isci.2020.101993>
 55. Kwak SS, Kim Y, Kim E, Shin C, Cho K (2013) What makes people empathize with an emotional robot?: The impact of agency and physical embodiment on human empathy for a robot. In: 2013 IEEE RO-MAN, pp 180–185. <https://doi.org/10.1109/ROMAN.2013.6628441>
 56. Jung M, Hinds P (2018) Robots in the wild: a time for more robust theories of human-robot interaction. *ACM Trans Hum-Robot Interact* 7(1):2–125. <https://doi.org/10.1145/3208975>
 57. Strohkorb S, Fukuto E, Warren N, Taylor C, Berry B, Scassellati B (2016) Improving human-human collaboration between children with a social robot. In: 2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN), pp 551–556. <https://doi.org/10.1109/ROMAN.2016.7745172>
 58. Jung MF, Martelaro N, Hinds PJ (2015) Using robots to moderate team conflict: the case of repairing violations. In: Proceedings of the tenth annual ACM/IEEE international conference on human-robot interaction. Association for Computing Machinery, New York, pp 229–236. <https://doi.org/10.1145/2696454.2696460>
 59. Short E, Mataric MJ (2017) Robot moderation of a collaborative game: towards socially assistive robotics in group interactions. In: 2017 26th IEEE international symposium on robot and human interactive communication (RO-MAN), pp 385–390. <https://doi.org/10.1109/ROMAN.2017.8172331>
 60. Donatelle RJ, Thompson AM (2010) *Health: the Basics*, Fifth Canadian Edition, 5th, edition. Pearson
 61. Card sorting: Current practices and beyond - JUX. Publication Title: JUX - The Journal of User Experience (2008)
 62. Amirova A, Rakhymbayeva N, Yadollahi E, Sandygulova A, Johal W (2021) 10 years of human-Nao interaction research: a scoping review. *Front Robot AI* 8
 63. Pot E, Monceaux J, Gelin R, Maisonnier B (2009) Choregraphe: a graphical tool for humanoid robot programming. In: RO-MAN 2009—the 18th IEEE international symposium on robot and human interactive communication, pp 46–51. <https://doi.org/10.1109/ROMAN.2009.5326209>
 64. Tärning B, Tjøstheim TA, Johansson B (2019) Communicating emotional state and personality with eye-color and light intensity. In: Proceedings of the 7th international conference on human-agent interaction. HAI '19. Association for Computing Machinery, New York, pp 214–216. <https://doi.org/10.1145/3349537.3352769>
 65. Xu J, Broekens J, Hindriks K, Neerinx MA (2014) Robot mood is contagious: effects of robot body language in the imitation game. In: Proceedings of the 2014 international conference on autonomous agents and multi-agent systems. AAMAS '14. International Foundation for Autonomous Agents and Multiagent Systems, Richland, pp 973–980
 66. Xu J, Broekens J, Hindriks K, Neerinx MA (2013) Mood expression through parameterized functional behavior of robots. *IEEE Ther Exp Psychiatry* 25(1):49–59. [https://doi.org/10.1016/0005-7916\(94\)90063-9](https://doi.org/10.1016/0005-7916(94)90063-9)
 68. Barrett LF, Russell JA (1999) The structure of current affect: controversies and emerging consensus. *Curr Dir Psychol Sci* 8(1):10–14. <https://doi.org/10.1111/1467-8721.00003>
 69. Sy T, Côté S, Saavedra R (2005) The contagious leader: Impact of the leader's mood on the mood of group members, group affective tone, and group processes. *J Appl Psychol* 90(2):295–305. <https://doi.org/10.1037/0021-9010.90.2.295>
 70. Becker DV, Srinivasan N (2014) The vividness of the happy face. *Curr Dir Psychol Sci* 23(3):189–194. <https://doi.org/10.1177/0963721414533702>
 71. Hatfield E, Bensman L, Thornton PD, Rapson RL (2014) New perspectives on emotional contagion: a review of classic and recent research on facial mimicry and contagion. *Interpers Int J Personal Relationships* 8(2):159–179. <https://doi.org/10.5964/ijpr.v8i2.162>
 72. R core team (2022) R a language and environment for statistical computing. R foundation for statistical computing, Vienna. <https://www.r-project.org/> Accessed 2023-09-18
 73. Revelle W (2023) *Psych: Procedures for psychological, psychometric, and personality research*. <https://cran.r-project.org/web/packages/psych/index.html> Accessed 18 Nov 2023
 74. Rosseel Y (2012) Lavaan: an R package for structural equation modeling. *J Stat Softw* 48:1–36. <https://doi.org/10.18637/jss.v048.i02>
 75. Bentler PM, Chou C-P (1987) Practical issues in structural modeling. *Sociol methods Res* 16(1):78–117
 76. Korkmaz S, Goksuluk D, Zararsiz G (2014) MVN: an R package for assessing multivariate normality. *The R J* 6(2):151–162
 77. SEM: Measuring model fit (David A. Kenny). <http://www.davidakenny.net/cm/fit.htm> Accessed 2023-09-18
 78. Zhao J, Lv Y, Zeng Q, Wan L (2022) Online policy learning based output-feedback optimal control of continuous-time systems. *IEEE Trans Circuits Syst II Express Briefs policy learning based output-feedback optimal control of continuous-time systems*. *IEEE Transactions on Circuits and Systems II: Express Briefs* (2022)
 79. Strack F, Martin LL, Stepper S (1988) Inhibiting and facilitating conditions of the human smile: a nonobtrusive test of the facial feedback hypothesis. *J Pers Soc Psychol* 54(5):768–777. <https://doi.org/10.1037/0022-3514.54.5.768>
 80. de Beir A, Cao H-L, Gómez Esteban P, van de Perre G, Lefebvre D, Vanderborcht B (2016) Enhancing emotional facial expressiveness on NAO. *Int J Soc Robot* 8(4):513–521. <https://doi.org/10.1007/s12369-016-0363-x>
 81. Reimann M, Graaf J, Gulik N, Van De Sanden S, Verhagen T, Hindriks K (2023) Social robots in the wild and the novelty effect. In: *International conference on social robotics*. Springer, pp 38–48
 82. Smedegaard CV (2019) Reframing the role of novelty within social HRI: from noise to information. In: 2019 14th ACM/IEEE international conference on human-robot interaction (HRI). IEEE, pp 411–420
 83. Bailey J (2023) Ai in education: the leap into a new era of machine intelligence carries risks and challenges, but also plenty of promise. *Educ Next* 23(4):29–36
 84. Blease C, Torous J (2023) ChatGPT and mental healthcare: balancing benefits with risks of harms. *BMJ Ment Health* 26(1)
 85. de Rooij A, van den Broek S, Bouw M, de Wit J (2023) Co-designing with a social robot facilitator: effects of robot mood expression on human group dynamics. In: Proceedings of the 11th international conference on human-agent interaction. HAI '23. Association for Computing Machinery, New York, pp 22–29. <https://doi.org/10.1145/3623809.3623820>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Alwin de Rooij is an Assistant Professor in creativity research at Tilburg University and Associate Professor in Situated Art and Design at Avans University of Applied Sciences, the Netherlands. His research focuses on understanding and augmenting creativity in art and design.

Simone van den Broek is a lecturer and applied researcher at Avans University of Applied Sciences, the Netherlands. She works on design research projects that contribute to health and well-being, while also fostering user acceptance of emerging technologies. Her aim is to equip people with the skills and tools needed to enhance the quality of their daily lives.

Michelle Bouw is a research master student in linguistics and communication sciences at Tilburg University, the Netherlands. Her research focuses on business communication, persuasion, and digital media.

Jan de Wit is an Assistant Professor in human-centered and inclusive artificial intelligence at Tilburg University, the Netherlands. His research focuses on the design of engaging and effective human-agent interactions.