Exploring Collaborative Movement Improvisation Towards the Design of *LuminAI* — a Co-Creative AI Dance Partner

Milka Trajkova*
Georgia Institute of Technology
Atlanta, Georgia, USA
mtrajkova3@gatech.edu

Duri Long*
Northwestern University
Evanston, Illinois, USA
duri@northwestern.edu

Manoj Desphande
Georgia Institute of Technology
Atlanta, Georgia, USA
manojdeshpande@gatech.edu

Andrea Knowlton
Kennesaw State University
Kennesaw, Georgia, USA
agisekno@kennesaw.edu

Brian Magerko
Georgia Institute of Technology
Atlanta, Georgia, USA
magerko@gatech.edu

ABSTRACT

Co-creation in embodied contexts is central to the human experience but is often lacking in our interactions with computers. We seek to develop a better understanding of embodied human co-creativity to inform the human-centered design of machines that can co-create with us. In this paper, we ask: *What characterizes dancers' experiences of embodied dyadic interaction in movement improvisation?* To answer this, we ran focus groups with 24 university dance students and conducted a thematic analysis of their responses. We synthesize our findings in an Interconnected Model of Improvisational Dance Inputs, where movement choices are shaped by the interplay between in-the-moment influences between the self, partner, and the environment, a set of generative strategies, and heuristics for a successful collaboration. We present a set of design recommendations for *LuminAI*, a co-creative AI dance partner. Our contributions can inform the design of AI in embodied co-creative domains.

CCS CONCEPTS

• **Applied computing** → **Performing arts**; • **Human-centered computing** → **Empirical studies in HCI**; *Empirical studies in collaborative and social computing*.

KEYWORDS

co-creativity, co-creative agents, dance improvisation, movement improvisation, AI agents, computational creativity

ACM Reference Format:
Milka Trajkova, Duri Long, Manoj Desphande, Andrea Knowlton, and Brian Magerko. 2024. Exploring Collaborative Movement Improvisation Towards the Design of *LuminAI* — a Co-Creative AI Dance Partner. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24), May 11–16, 2024, Honolulu, HI, USA.* ACM, New York, NY, USA, 22 pages. https://doi.org/10.1145/3613904.3642677

*Both authors contributed equally to this research.

CHI '24, May 11–16, 2024, Honolulu, HI, USA

ACM ISBN 979-8-4007-0330-0/24/05
https://doi.org/10.1145/3613904.3642677

1 INTRODUCTION

Co-creativity—or collaboration in a real-time creative partnership—is common across many domains (e.g., dance, improvisation, sports, work, and play) and is how we socially make sense of our environment through interwoven exploration, reflection, and action. As common as this experience is in our daily lives, it rarely defines our interactions with computers. Furthermore, we have little understanding about how computers can co-create with us in *embodied* domains, or environments in which we create, manipulate, and share meaning "through engaged interaction with artifacts" [32]). While prior work has explored how to develop artificial intelligence (AI) systems that can generate art [74, 75, 104] and co-create with humans in domains like drawing and improvising music [26, 46], researchers have yet to explore how humans and AI agents can intertwine cognitive processes and knowledge with physical exploration and execution in a shared, creative environment.

We take a human-centered approach [97], seeking to develop a better understanding of embodied human co-creativity to inform the design of machines that can co-create with us. The end goal of our work–extending beyond the scope of this paper–is to develop a software architecture to facilitate the authoring of embodied interactive agents that can co-create with people in movement-based improvisational domains. This paper seeks to first develop an understanding of embodied co-creation within the domain of *movement improvisation*. While a variety of HCI research has explored how to design tools to enhance dance rehearsal and create novel performance experiences (e.g., [35]), to our knowledge, no prior work has contributed a practice-based understanding of collaborative human movement improvisation with implications for the design of co-creative AI.

We aim to answer the research question: ***What characterizes dancers' perceived experiences of embodied dyadic interaction in co-creative domains like movement improvisation?*** We conducted a set of focus groups with students in a dance BA program in the southeastern United States and completed a thematic analysis of participant responses. We synthesize our findings in a model of improvisational dance inputs where movement choices can be shaped by interplays such as in-the-moment influences between the self, partner, and the environment as well as a set of generative strategies and heuristics for a successful collaboration. We then present a set of design recommendations for *LuminAI*, a co-creative

AI dance partner. This paper contributes to the broader HCI research community a model of improvisational dance inputs that can be used to guide and inspire the design of future technologies in embodied improvisational domains. Our ongoing and future work takes a design research approach [128] to evaluate this model in practice by using it to guide the design of *LuminAI*.

2 FOUNDATIONAL RESEARCH

First, we present prior work that is foundational to our study design. We discuss a design artifact, *LuminAI*, that has motivated this work and provides a future use and evaluation context for the design recommendations we identify. In addition, we describe the movement theories that have informed the design of *LuminAI* and the *enactive cognitive framework of Participatory Sense-Making (PSM)*, a theory that guides our understanding of embodied movement improvisation.

2.1 Design Artifact: *LuminAI*

We have developed *LuminAI* (Figure 1), an interactive installation in which an AI agent–projected onto Holotronica's patented Hologauze scrim–can collaboratively improvise movement with a human partner using computational formalizations of improvisational movement theories from theater and dance [115]. The human's movements are tracked using motion capture technology. The AI can learn and reason about the human's movements using *Laban Movement Analysis* [60] and *Viewpoints* movement theory [11] (see 2.2), recall movements it has learned in the past, and generate new movements by transforming observed gestures.

We developed *LuminAI* from a top-down perspective based on our understanding of movement theory and some consultation with dance experts. We have previously evaluated *LuminAI* primarily with non-dancers. Here, we take a more human-centered approach [97] by involving dance students in the design process, allowing us to explore nuances of communication, coordination, and reasoning about movement that only arise after years of practice. This will allow us to eventually develop an agent more closely capable of expert-level movement improvisation and ensure the agent is useful to dancers. We reference our prior experiences with and future goals for *LuminAI* throughout the paper to contextualize our study and results.

2.2 Movement Theories

LuminAI utilizes two different movement theories, which also informed our focus group study and data analysis. Laban Movement Analysis (LMA) is a method and language for describing, visualizing, interpreting, and documenting human movement [60]. Developed by Rudolf Laban, LMA draws from his work in dance, choreography, and movement education. It encompasses several elements, including Body (identifying parts and movements of the body), Effort (concerning the dynamics of movement), Shape (the design in space and relation to the environment), and Space (paths and directions of movements). LMA is used in various fields, including dance, physical therapy, psychology, and animation, for understanding and interpreting human body movement.

Viewpoints is a movement theory primarily used in theatre and dance that focuses on exploring physicality and space [11]. It originated from the choreographic work of Mary Overlie, who broke down performance into six fundamental categories [11]. Later, theatre directors Anne Bogart and Tina Landau expanded it into nine viewpoints [11]. These viewpoints cover two categories: Time (including tempo, duration, and rhythm) and Space (including shape, gesture, architecture, spatial relationship, and topography). This theory allows performers to develop an intuitive understanding of movement and space, fostering improvisation and ensemble work in performance.

2.3 Enaction and Participatory Sense-Making

Our current work is grounded in the theory of *enactive cognition*, which argues that much of human cognition is determined by how our bodies are able to interact with the environment. According to enactivists, cognition involves a social process of *participating in each other's sense-making*, in which interactors are actively making sense of each other through interlaced processes of perception and action [27]. Interactors coordinate with each other using various methods, such as facial or vocal expression, eye contact, gesture, turn-taking, touch, and affect attunement [27]. Di Paolo and De Jaegher describe three levels of sense-making corresponding to the level of participation in a dyadic social interaction [27]. In *individual sense-making*, both individuals are not participating in creating a shared meaning and are mostly self-exploring. In *orientational sense-making*, one individual tries to influence or be influenced by another's sense-making activity. Finally, *joint sense-making* corresponds to the highest participation level in which we find complex cases where shared meaning emerges.

Some prior research has explored enactive cognition within the domain of dance improvisation. van Alphen et al. [118] studied participatory sense-making in the highly structured improvisational context of the tango, but little work to date has engaged in an in-depth study of participatory sense-making in open-ended improvisational dance. Savrami et al. [99] also call for more research relating enactivism to dance. The questions we included in our focus groups and, resultantly, some of the themes we identify reflect and attempt to understand how dancers engage in participatory sense-making.

3 RELATED WORK

In addition to the foundational research presented above, we first draw on a body of related literature on movement improvisation and dance technology followed by a review of work on embodiment, embodied human-agent interaction, and co-creative AI.

3.1 Studies of Dance Improvisation and Technology in Dance

We delve into dance improvisation studies to better understand the landscape of improvisation to inform the design and future use of embodied co-creative systems. This section defines dance improvisation, underscores its significance, outlines the challenges faced during the creative process, and highlights traditional and modern dance technologies.

Figure 1: Three Differents Variations of *LuminAI* projected onto the Hologauze scrim.

3.1.1 Definition. Improvisation is a rigorous form of creativity [2, 6], requiring actors to simultaneously manage multiple processes. This involves navigating the interplay between individual factors (such as skills, emotions, physical state) and environmental elements (like the actions of fellow performers, positioning of objects, and the surrounding space). Dance improvisation, described as the spontaneous "movement of the moment" [10], is the real-time creation and performance of unplanned movement [2, 16]. It demands immediate action and interaction, involving complex coordination and alignment between dancers [44, 84, 87, 94, 118].

3.1.2 Importance and Use. Dance improvisation is crucial for artistic exploration, cultural preservation, and dance innovation [1, 67, 93, 94, 118]. It enhances creativity, allows movement exploration, and fosters personal expression [30, 111]. Beyond artistic expression, it plays a therapeutic role, aiding populations like those with early-stage dementia and Parkinson's Disease [45, 66]. In essence, dance improvisation serves as a tool for exploration, connection, and emotional resonance, with implications for both artistic and therapeutic domains.

3.1.3 Challenges. Creativity in dance is complex, intertwined with the environment, the dancer's cognition, and external technologies [111]. Prior work highlights challenges dancers currently face while improvising, which can impact their creative process and performance. These include: the pressure of originality, potentially causing performance anxiety and self-censorship [30]; the need for effective coordination, mutual agreement, and synchronization during dyadic improvisation [84]; the balancing act of employing constraints to guide movement, while ensuring motor creativity [110]; habitual repetition of certain movements which can restrict improvisation [43]; and challenges in integrating technology in dance, which can introduce surveillance concerns and shape digitally-mediated identities [7]. Acknowledging these challenges is vital for the development of embodied co-creative tools.

Overall, there is a lack of understanding in the the basis of improvisational choices among dancers, spanning the individual, their partner, and environmental influences. To develop improved AI solutions, we need to delve deeper into the factors affecting face-to-face dyadic interactions.

3.1.4 Genesis of Dance Technology and AI Application. Dance has been influenced by both traditional tools, like mirrors [28, 114], and modern technologies, including motion capture and virtual reality [113]. Digital technologies in the dance domain range from tools aiding creative composition and enhancing stage performances with visual and auditory elements, to environments supporting dance education and practice, systems for movement documentation and analysis in research, and digital games centered around dance themes [90]. Examples by [91] and [127] are specific to improvisation. Recent studies highlight AI's diverse applications in dance, from movement recognition to online teaching platforms [50, 56, 76, 112, 121, 124–126]. These technologies, however, do not incorporate AI-driven decision-making for improvisation.

3.2 Embodiment in Technology Design

The concept of embodiment in design has garnered significant attention in recent years, particularly in the integration of bodily experiences into technological interfaces. Dourish [31] posits that meaning is constructed through our physical and social, or "embodied," interactions with the world. More recently, the phrase "embodied interaction" has been applied to describe interactive installations that respond to hand gestures and body movements [49] [112] [17]. Mueller et al. [79] explored a more humanized technological future by embracing the human body as both a "Körper" and "Lieb." The Körper perspective refers to the physical body, while the Leib perspective refers to the lived body with feelings, sensations, perceptions, and emotions. They push designers to embrace the body as digital play. This aligns with the notion of somaesthetic

appreciation design proposed by Höök et al. [48], which focuses on designing for the aesthetic and sensory experiences of the body in interaction with technology. Additionally, Spiel delves into the importance of considering the diversity of bodies in the design of embodied interaction, highlighting the need for inclusivity and sensitivity to various bodily experiences [107]. These papers collectively underscore the significance of considering the body as a central element in the design of interactive systems, and, pushing beyond earlier research on tangible and embodied interaction (TEI), they emphasize the need to account for diverse and multifaceted bodily experiences and the potential for technology to facilitate embodied play and aesthetic appreciation [79] [98].

Furthermore, Roth [98] provides insights into the role of gestures in teaching and learning, shedding light on the embodied nature of communication and knowledge transmission. This aligns with the broader theme of embodiment in design, emphasizing the interconnectedness of bodily experiences, communication, and learning processes. The synthesis of these papers underscores the multifaceted nature of embodiment in design, encompassing sensory experiences, inclusivity, bodily diversity, and the role of gestures in communication and learning [81].

3.3 Embodied Human-Agent Interaction

In the realm of interactive technology, the advancement of natural user interfaces has significantly changed how we engage with virtual agents and robots. Moving beyond the limitations of mouse and keyboard, these interfaces incorporate speech, touch, and gesture controls, enhancing user experience. Virtual reality (VR) games epitomize this evolution, offering players immersive experiences where physical actions like flipping burgers [105] or climbing Mt. Everest [109] are mirrored in the virtual environment. However, the integration of computational agents that can match human players in terms of embodied interaction is still in its infancy.

Embodied interaction is also prominent in creative domains like interactive art and improvisational theater. Installations such as "A Delicate Agreement" [68] use eye-tracking and gaze-based interactions for narrative engagement, while "Three Line Scene" [85] employs full-body gestures for theatrical improvisation with micro-agents. Similarly, "Shimon" [47], a robotic entity, uses sound localization and beat detection to interact and collaborate in musical settings.

Previous research has explored the potential of embodied interaction in various contexts. Studies from our research group have looked into using embodied human-agent interaction for scene partners in virtual environments [52] and as co-creative dance partners in public interactive settings [53]. These explorations have laid the groundwork for further research, particularly in understanding the nuances of advanced human dancers and their co-creative sense-making processes. Such studies are crucial for enhancing the design and functionality of computational agents, aiming to achieve a more nuanced and human-like interaction in various domains. However, we have yet to explore how studies of advanced human dancers and their dyadic co-creative sense-making processes can inform the design of these agents.

3.4 Co-Creative AI

Initial steps towards co-creative human-computer interactions have been made in the study of co-creative agents (i.e., computer programs that collaborate with humans on a creative task). These agents engaged users in an interactive dialogue—typically in a virtual environment—where creation, suggestion, and selection of creative content ebbs and flows between the user and the computer. Co-creative agents have been developed and studied in creative domains ranging from music improvisation [9, 46] to improv theater [69, 72, 73, 86], dance [53], game development [42, 64], collaborative storytelling [71], and collaborative drawing [26, 29]. In the dance domain, Alfaras et al. [3] utilized sensors as part of dance performances, investigating the integration of biodata into artistic expression. Their work focused on designing interactive systems that provide visual feedback on movement qualities in contemporary dance groups. Several frameworks have been created to guide the development of co-creative AI [40, 80, 95], although none deal explicitly with embodied interaction or improvisation.

Our research contributes a novel model that is explicitly focused on how co-creation occurs in embodied, improvisational contexts, towards the goal of developing a co-creative AI dance partner.

4 FOCUS GROUPS

We collaboratively identified seven key topics of interest related to embodied movement improvisation that we wanted to investigate further in our focus groups. We identified these topics based on a combination of literature and practice. Certain topics were motivated more by practice–for instance, we have previously developed systems for modulating AI agent *leading/following* behaviors, but they have had mostly negative impacts on user experience [59, 122], motivating a need to better understand leading/following practices in dance. Other topics were motivated more by literature–for instance, understanding *focus* and *interaction dynamics* are central to the process of participatory sense-making [38] and have been understudied in the domain of embodied movement improvisation. An initial set of topics was identified by authors Long and Magerko. These were then iteratively refined and elaborated upon in group meetings with the rest of the authors. Each topic is described in Table 1. A full list of questions related to each topic is in the supplemental materials.

4.1 Participants

We recruited college-level Dance BA students from Kennesaw State University, a university located in the southeastern United States outside of Atlanta, GA. We anticipated that these students, while experienced enough to provide valuable insights, would maintain a learner's perspective, avoiding an 'expert's blind spot' [13].

We first conducted three focus groups with six dancers each, covering two topics (from Topics 1-6) per group (see Table 1). We then conducted three additional sessions with two dancers each to cover *Topic 7: Interaction Dynamics*. We worked with smaller groups for this last topic because we were also collecting motion capture data during these sessions (not discussed within the scope of this paper).

In total, 24 dance students aged 18-41 ($\overline{x} = 21$) participated in our studies, of whom 22 used she/her pronouns, one he/him, and

Topic	*Knowledge Goal*	*Design Goal*
1. Focus	Understand how dancers shift their focus from the self to their partner to the environment.	Improve agent responsiveness and awareness
2. Communication Techniques	Understand how dancers use full-body actions, sound, noise, and eye contact to communicate, what modes of communication are most effective, how communication differs between partners, the role of physical touch, and the role of a prior relationship with a dance partner.	Enable effective human-AI communication
3. Leading/Following	Understand how and why dancers shifted from leading to following during the collaboration, how they shift between leading/following in class or rehearsal, how they signal or notice shifts in leader/follower behavior, and what leading/following looks like.	Enable naturalistic turn-taking
4. Introducing New Ideas	Understand how dancers introduce new ideas, how they communicate a shift to a new motif to their partner, how long they spend exploring a particular motif, when they abandon and/or return to an idea, and how ideas evolve. A motif in dance is a movement idea that can be developed over time. They are "organizing devices that give the artist's imagination a start, and so 'motivate' the work. They drive it forward, and guide its progress [61].	Allow *LuminAI* to detect and build on motifs
5. Recognizing Value	Understand how expert improvisers recognize when a move or an improvisation session is of high value, what this looks like in the moment, and what factors contribute to a 'good' improvisation session.	Allow *LuminAI* to self-evaluate and determine when a percept is of high value
6. Movement Strategies	Understand how dancers think of their next movement, what movement qualities they consider when observing or performing movements, how they build on their partners' movements, and what constitutes a gesture. Identify common generative movement strategies.	Validate existing response strategies used by *LuminAI*; identify new strategies and reconsider how we define gestures
7. Interaction Dynamics	Understand whether/how dancers shifted between being disengaged from their partner, actively observing their partner, and mutually incorporating each others' expressions and actions into their own bodies; shifts between physical action and mental reflection; shifts between focused improvisation or *flow* [24] vs. a state of exploration and ideation.	Allow *LuminAI* to participate fluidly in participatory sense-making

Table 1: Seven Key Topics Explored in the Focus Groups

one she/her/they/them. Almost all (23/24) students were pursuing a major in dance and had numerous years of experience in modern/contemporary dance ($\overline{x}$ = 9 years) and other styles (see Figure 2) with an average of 14 years of dance experience across all participants. Participants reported training for an average of 12 hours per week. Six participants reported current injuries (e.g., shin splints, tendonitis), and 10 participants indicated prior injuries that influenced their dancing.

4.2 Study Design

We asked students to participate in 5-8 minute improvisational games. The games were designed by author Knowlton, a Professor in the collegiate dance BA major program at Kennesaw State University. The games gave dancers a concrete exercise and provided shared experiences to reflect upon. as explicit reflection after each exercise is not always common in regular dance practice [67]. Dancers engaged in the games as pairs, while the other dancers in the session observed. We alternated between having the mirrors in the dance studio open vs. closed between pairs to see if collaboration dynamics were affected by the mirror. Detail on exactly when mirrors were open vs. closed is provided in the supplemental materials. After the session, dancers participated in a semi-structured focus group. We chose the group setting to reduce intimidation and foster ideation. Although group discussions can lead to participants' unduly influencing each others' opinions, we aimed to mitigate this as facilitators.

The games and prompts given to dancers for each topic are described in detail in the supplemental materials. For example, for Introducing New Ideas, we asked dancers to participate in a game called *Exhaust the Motif*, in which one dancer introduces a basic motif. Together, the two dancers let the motif develop in complexity until it can accumulate and elaborate no further. Dancers may introduce a new motif at any time. We asked dancers to pay attention to when they introduced or moved onto a new idea.

4.3 Data Analysis

Focus group sessions were recorded, and recordings were transcribed prior to analysis. We used *thematic analysis* to identify common themes from the focus groups. Our thematic analysis approximated the *codebook* approach described by Braun and Clarke, in which researchers "use some kind of structured coding framework...but consensus between coders and inter-rater reliability are not usually measures of quality. Themes are typically initially developed early on...but...can be refined or new themes can be developed through inductive data engagement..." [14].

More specifically, our seven high-level topics (e.g., Focus, Introducing New Ideas) served as early, deductive themes that guided our coding process (See Table 1). However, within each topic, we

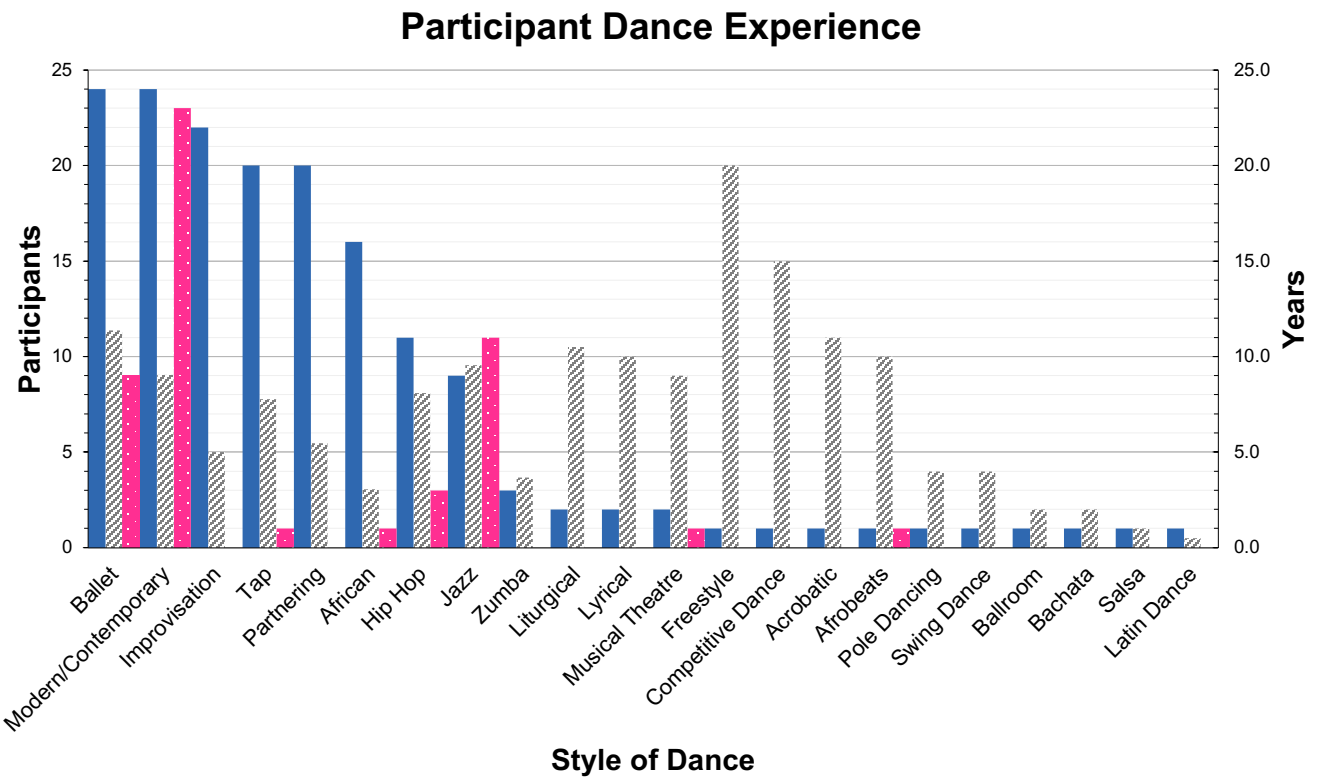

Figure 2: Summary of focus group participants' prior dance training.

used an inductive process to generate themes by interpreting the data. All authors engaged with the transcripts and identified *codes* (capturing single observations) within a collaborative document [14]. Then, we collaboratively grouped codes that reflected shared meaning into higher level *themes* [14].

The process of grouping codes into themes was started asynchronously in a collaborative document, with calibration during weekly virtual team meetings. Disagreements between team members were resolved through group discussion. We then met weekly over the course of several months to iteratively construct a diagram depicting the relationship between themes (see Figure 4), as we found that themes did not neatly fit within the seven focus group topics and instead were cross-cutting. Constructing the diagram aided in clarifying our descriptions of the themes and ensuring they each described distinct patterns from the data.

We acknowledge that in thematic analysis, researchers' backgrounds and interpretative lenses play an important role in data analysis [14]. To aid the reader in interpreting our results, we provide context on the authors' backgrounds. Author Trajkova holds a Ph.D. in Human-Computer Interaction and has a background as a professional ballet dancer. Author Long holds a Ph.D. in Human-Centered Computing and has a background in computer science and theater. Author Deshpande is a doctoral candidate studying AI and digital media and has a background in architecture and information technology. Author Knowlton is a dance professor with 33 years of dance training and has previously worked with most of the students in the study. Author Magerko holds a Ph.D. in Computer Science, has a background in computer science and cognitive science, and has many years of experience working on projects involving cognitive science, co-creative AI, museum/art installations, and creative CS education.

5 RESULTS

We present the themes we identified in a summative diagram, which represents an Interconnected Model of Improvisational Dance Inputs (see Figure 4). The interconnected components are singled out in Figure 3. This model suggests that movement choices are shaped by three elements: 1) *in-the-moment influences*; 2) *generative strategies*, and 3) *heuristics for a successful collaboration*. These elements are interdependent and range in scope from momentary inputs to

high-level guiding principles. This model is not exhaustive and represents the insights collated from this specific ensemble of dancers. Future work could expand this model with additional perspectives, especially from other forms of improvisational dance.

5.1 In-The-Moment Influences

In-the-moment influences refer to elements that precipitate immediate alterations in a dancer's progression throughout an improvisational session. We have grouped these elements into three categories: 1) *self*, referring to influences originating from a dancer's personal experience; 2) *partner*, referring to influences from the interpersonal collaboration between dancers; and 3) *environment*, referring to influences from the surrounding atmosphere.

5.1.1 Self. In this section, we discuss themes related to dancers' experience of the self and their relationship to their own bodies and feelings during the improvisation.

Bodily Sensation: Personal bodily sensations affect movement choices and focus. Dancers discussed how their personal bodily sensations influenced their movement choices. For instance, one participant described how her focus was being pulled by her body: "...I was focusing too much on, 'Am I breathing too loud? My bones are cracking, it's echoing'"(P3, Focus). Another participant discussed how current injuries affected her movement choices: "So I have injuries in both of my knees right now, and it's fine right now, but I was just trying to watch that. So I wasn't trying to go too fast or do too much, any jumps or anything..." (P2, Focus). Another dancer related to this, saying "...I had a loud hip pop on one of my movements. And so then I think subconsciously, I was like, 'Okay, we're not going upside down anymore, we're not lifting up our legs anymore after this.' So then I think I kept my movements smaller and more internal" (P4, Focus).

Positive sensations also influenced choices. When expanding on a comment she made about having a 'good day,' one participant described bodily sensations as a factor: "Like the sun is out and it just feels good or it could also mean that my body just feels really good that day..." (P5, Interaction Dynamics). Another participant echoed this sentiment, "I feel my improv is just how my body feels that day. Like if I'm good at my balance that day or if I'm feeling really flexible that day, then I'll just run with whatever my body is feeling" (P5, Introducing New Ideas).

Emotion: Emotions can both spur new ideas and set the tone for the improvisation. Emotion and bodily sensations are intertwined, yet distinct. Here, we refer to emotions as more 'mental' (happiness, frustration), and sensations as 'physical' (soreness, balance). Dancers often ambiguously described emotions ("it felt good"; "it sparked emotion"). Author Knowlton speculated that dancers might use these terms due to an inability to articulate their choices intentionally. Many dancers revealed that group reflection in a dance setting was a novel experience, providing valuable insights in verbalizing movement choices.

However, emotions significantly influenced dancers' movement decisions. One dancer explained how her day's quality impacted her dance: "...it really just depends on the day, like if I'm having a good day...I can feel it reflect in my body and like my improv just because I want to express that..." (P6, Interaction Dynamics). Another dancer added, "dance is also used as like a form of like therapy for myself...It just changes your...the way you think about improv, depending on what's going on through the day" (P5, Interaction Dynamics). Both P6 and P5 concurred that "good vs. bad" could pertain to mood or physical state.

In other discussions, dancers emphasized how movement generates emotion. One dancer mentioned revisiting a movement due to the emotion it evoked: "...I guess [I would return to] something that also sparks emotion in me because I have to have some reason that it's pushing the movement along. And oftentimes, it has to do with an emotion or a feeling or a sensation or something..." (P4, Introducing New Ideas).

Self-Focus: Focus on the self can provide inspiration, but can also distract from the partnered collaboration. Dancers discussed how their focus shifted between themselves, their partner, and the environment. Oftentimes, focusing too much on the self was mentioned as a source of distraction: e.g., "I tried to keep my focus on my partner pretty much the majority of the time...but I definitely strayed from the prompt I think when I was focusing more on myself..." (P6, Focus); "When I stopped looking at myself in the mirror, then I started getting inspiration from the outside" (P5, Focus). Control over focus is a skill that is honed through years of improvisation training [120], and author Knowlton pointed out that she often gives her students prompts during class to direct their focus—e.g., "keep noticing your partner," "don't get too internal."

Some discussed an excessive focus on the self as a marker of poor improvisation ("I guess for me it [a bad improv session] kind of more so felt like two solos rather than it being like a partnering type thing..." (P2, Recognizing Value)). This is corroborated by existing literature on improvisation in other domains, which describes good improvisation as a process of constant attention switching between self and others [77]. On the other hand, some dancers noted how focusing on the self could at times provide inspiration–e.g., "I started finding inspiration from...myself, seeing myself in the mirror" (P5, Focus).

Dancers also reported differences between experimenting alone and with a partner (i.e., siloed vs. partnered play [25]). One participant said dancing alone allowed her to experiment with movements she had not yet mastered, "I also feel like if I'm by myself...I'm more likely to experience and try new moves...It's like free no judgment zone, because you're not having to worry about someone being around" (P3, Movement Strategies).

Continuous Motion: Dancers do not appear to reason about their movement as a series of discrete gestures. We asked dancers about how they defined a gesture and marked shifts between different gestures. Dancers had conflicting interpretations of what a 'gesture' was, with some conceptualizing gestures as everyday interactions like waving or lifting a coffee cup (P5, Movement Strategies), others thinking of gestures as isolated movements, such as the arm moving while the rest of the body stays still (P2, Movement Strategies), and still others talking about gestures as full-body movement with a discrete beginning and end, like a jump (P3, P1, Movement Strategies).

While some of this confusion may have stemmed from terminology, it was clear that while some dancers described their improvisation as being "like...a conversation" (P3, Movement Strategies)

Figure 3: Breakdown of the interconnected components of the model.

or a "movement sequence" (P2, Movement Strategies), they did not conceptualize their interactions as a series of discrete gestures. Transitions between movements were more fluid and could be interpreted in multiple ways.

5.1.2 Partner. This section explains the dancer's experience with their partner and how their relationship shaped their communication strategies and the shared memories they drew on during the session.

Prior Relationships and Mutual Knowledge: Prior relationships and shared artistic collaboration (e.g., classes taken together) influenced dancers' choices and level of comfort and trust due to shared movement vocabulary, technique, and memories. In our sessions, we inquired about pairs' familiarity with each other. Four duos had a 2–4 year dance history, three pairs had danced together for 1-8 months, and nine pairs were first-time collaborators.

Previous shared experiences, whether in class or rehearsal, provide a reservoir of shared movements, techniques, and choreographies. One dancer emphasized the significance of shared dance settings, "I think that knowing each other like in a dance setting for so long, made it comfortable to just kind of bounce off of each other. Even if we're not super close socially, there's some kind of other connection that just comes with dance" (P4, Introducing New Ideas).

Dancers can leverage past collaborations. One dancer noted, "I've been training her in my movement because she's been in my rehearsals. It was nice to improv with her and see her own movement...I focused on let me see hers and how I can take that with me and embody her movement" (P5, Introducing New Ideas).

Existing relationships bolster trust and comfort, crucial for touch or weight sharing in dance. Familiarity helps dancers gauge each other's comfort zones, ensuring a more seamless interaction. The significance of consent and awareness was highlighted by many. P5 mentioned being "hyper aware of your partner," and P1 talked about "being smart with your choices." P3 elaborated on the ease of interaction with familiar partners, "And I think that is easier with someone that you do know... it's okay if you want to kind of make contact. With someone you don't know, it's a little bit harder..."

Eye contact: Prolonged eye contact is often used to indicate moments of connection, transition, pacing, and vulnerability. Direct eye contact in dance was infrequent but, like touch, signified profound connection and transition. This finding is corroborated by prior work that shows that eye contact plays an important role in jazz and theater improvisation [100, 103]. P5 (Interaction Dynamics) remarked, "I feel for me, the way... when I do feel in tune with my partner is when I have eye contact with them...Because like you're looking at their eyes, you can read a lot through someone's eyes."

This gaze occasionally signaled the start of a joint movement, suggesting its role as a non-verbal agreement cue, aiding dancers in movement synchronization. It also marked mutual consent to transition, "I think that energy, like whatever we were doing, the energy we kept going in this crescendo like she said and coming down. And when we came down, then it was like okay, then we would make eye contact or something. See, okay, this is where we're going to go with it and we moved into something else" (P2, Introducing New Ideas).

Eye contact is a silent communication medium, guiding dancers' movement pace. One dancer detailed, "I remember a specific moment where we grabbed hands and pulled closer and we kind of got eye contact for a second and like that's when I slowed down..." (P1, Communication Techniques). This shared gaze fosters intimacy. Immersed in their partner's eyes, dancers can feel isolated from their surroundings, experiencing an amplified connection, making them feel they are the "only two people in the room" (P3, Recognizing Value).

Shifting Bodily Cues: Slowing down, stillness, and repetition can indicate a desire to shift ideas or have the partner take over leadership. Dancers utilized specific somatic strategies like slowing down, embracing stillness, and repetition as non-verbal cues in their improvisation. Slowing down often signaled a dancer's intent to transition to a passive role, allowing their partner to lead: "I would just slow down. If I was following, I would slow down and let her take over" (P2, Leading/Following).

Stillness acted as a reset, offering a moment of reflection and paving the way for subsequent movements. P5 (Introducing New Ideas) mentioned, "I think we just stopped and reset or introduced it slowly with another idea if it tagged along with the previous movement."

Repetitive movements signaled a need for change or evolution in the dance. Recognizing such patterns prompted dancers to either modify their movements or let their partner introduce fresh elements, ensuring the improvisation stayed dynamic. P6 (Introducing New Ideas) observed, "When I found myself doing the same pathways or the same type of movements, I was like okay, maybe it's time to switch to something else."

Mutual Touch Communication: Dancers intentionally communicate with each other using touch. Touch, like eye contact, was a rare but significant form of communication. Dancers explained how physical contact enhanced the likelihood towards shared timing of physical connection, referencing prior experience with contact

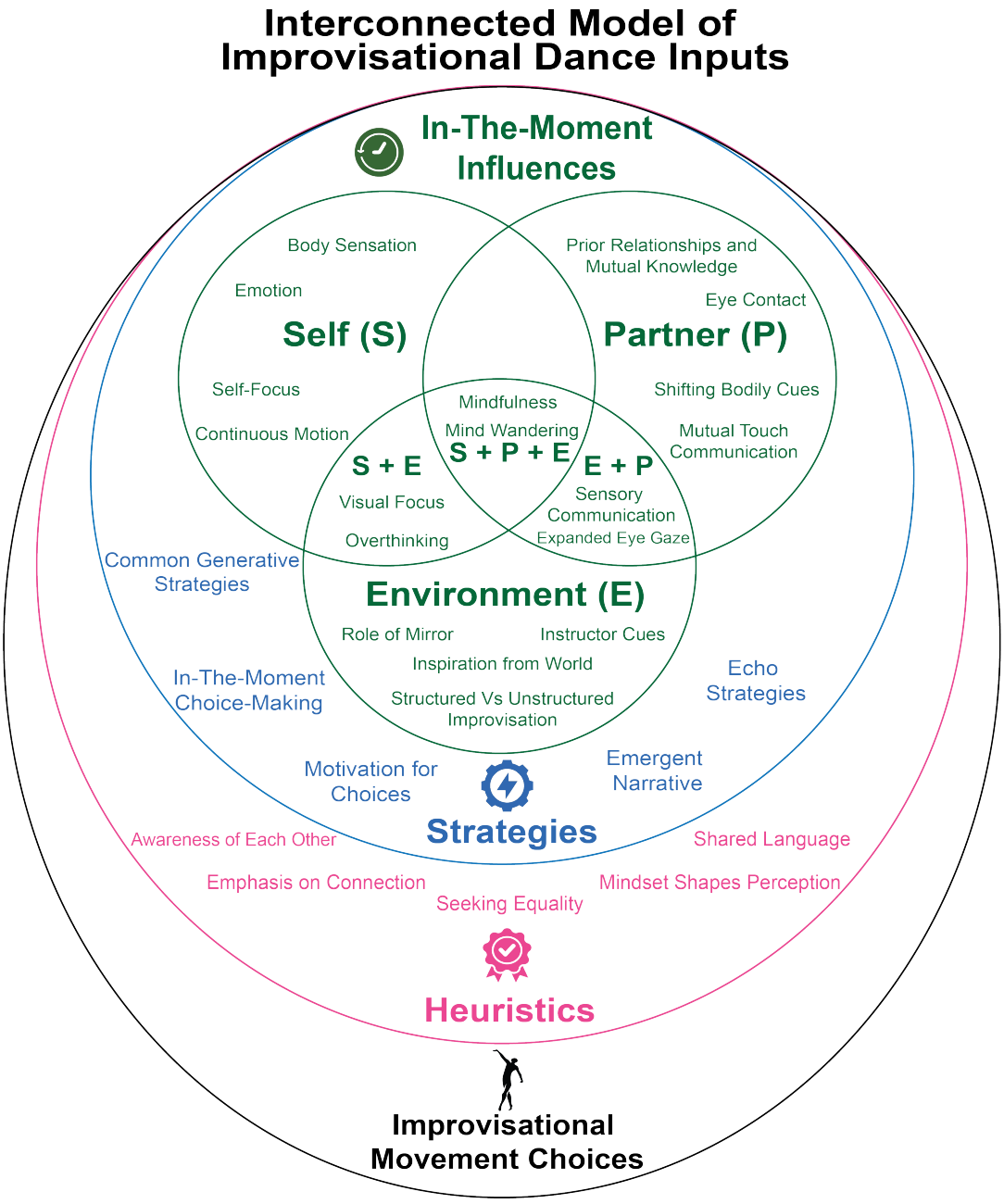

Figure 4: Interconnected Model of Improvisational Dance Inputs depicting the relationship between themes.

improvisation. As one dancer explained, "And I think [in] contact improv, that happens more frequently too. When you can touch a person, you're more likely to sync up" (P9, Interaction Dynamics). Contact improvisation invites dancers to engage in physical contact with their partners, fostering immediate and responsive communication. The tactile exchange enables dancers to feel each other's movement dynamics, balance, and intentions, making it easier to achieve a harmonious flow of movement.

Touch also affected the energy exchange between dancers. P1 observed that there was a big difference in energy between "partnering...[with] touch, physically and...partnering [where you are] just relating to each other not touching" (Leading/Following). Physical contact amplified mutual understanding, allowing dancers to connect at a deeper level and share their weight more intimately. Conversely, the absence of touch may necessitate other forms of communication to achieve similar levels of energy exchange.

5.1.3 Environment. This section delves into the dancers' experience interacting with their immediate environment–e.g., components found in the dance studio, cues from an instructor–and how this interaction impacted their focus, idea generation, and collaboration.

Role of the Mirror: Presence of the mirror can draw focus away from collaboration and heighten focus on self. Dancers frequently mentioned how mirrors shifted their attention from the collaboration to self-focus. Prior work also indicates that mirrors can play a role in distraction and enabling focus on the self [19] [89]. One dancer felt the mirror prompted self-evaluation, stating, "I think we're so used to coming into class...and facing the mirrors and also being able to evaluate what we look like based off of the mirrors...So not having them definitely makes it a little bit more intrinsic and also takes your focus away from that being the front" (P4, Focus).

The mirror's presence habituated dancers to face it, even in improvisation where no true front exists. Participants observed that they subconsciously turned towards the mirror, diverting their cognitive effort from the partnership. In contrast, the non-mirrored group experienced unrestricted movement exploration, focusing more on their partner. P8 (Focus) remarked, "I think it was interesting because even if the mirror is covered...I subconsciously automatically turn that way...So I think this allowed me to face different ways and get that out of my head." Further insights on the mirror's influence on movement can be found in 5.1.4.

Inspiration from the World: Dancers draw inspiration from objects/aspects in the environment and move from the outer world to the inner world. The participants discussed how various aspects of the environment, such as the room, floor, lights, and other people in the room, impacted their focus. Interacting with the environment is a multi-sensory experience—it allows individuals to take in sound, touch, sight, and smell that facilitates sensations in the moment [15]. Dancers mentioned that the use of these elements in the outer world inspired new ways to think about the kinesthetic sensation or the inner world of the movement. The haptic and visual stimulation from the environment creatively inspired dancers. For example, one dancer discussed the impact of textures in the room that drives their movement choices, "So if there's harsh lines, vertical or horizontal, I will take inspiration that way. But say there's something more fluid or falling like a more natural curve in front of me, sometimes that will impact the way that I'm dancing as well. It's like whatever I'm seeing around me" (P9, Interaction Dynamics).

Unstructured vs Structured Improvisation: Structured improvisation (i.e., focusing on the prompt) creates a shared language whereas unstructured improvisation (i.e., in-the-moment choices) induces agency and freedom of choice. Movement improvisation varies between structured (prompt-guided) and unstructured (open-ended). Structured prompts, like those given to our participants, allowed dancers to "put [themselves] in a mindset, get my energy there, and give me points where I can be slow and where I can be high energy just to gauge my energy throughout the time [of the improvisation]" (P3, Introducing New Ideas). Dancers felt structured prompts honed focus, especially during initial improvisation learning phases (P1, Communication Techniques).

Structured improvisation acts as a cognitive anchor, helping dancers maintain focus amidst potential distractions. One dancer, distracted by room textures, was re-centered by the prompt: "I was thinking about angles and then I would get distracted by textures, and then I'd be like, 'Okay, wait, no, we're doing angles and shapes.' So then I would go back" (P1, Focus). This highlights structured improvisation's role in ensuring focus and thematic consistency.

Conversely, dancers felt unstructured improvisation granted autonomy. Open-ended sessions might offer "more organic possibilities than if you were forced to have to touch and then you have to figure out, okay, we have to touch. So it feels [like] something we have to do. But in this instance, we were given the option and we wanted to, and we were let to. It's organic rather than constrained" (P1, Communication Techniques). Another dancer felt unstructured improvisation "flows better," implying directive-induced pressure can obstruct questions of "how are we going to get there or how is it going to flow and the momentum" (P6, Communication Techniques).

Instructor Cues: A dance instructor's verbal and gestural cues during the improvisation session serves as a third perspective providing constructive feedback and instructional guidance. Dance instructors leverage instructional cues to provide dancers with an improvisational roadmap. Cues prompt exploration, concentrate dancers' attention for sustained sessions, and create a loose structure to create within. Yet, cues do not stipulate an exact blueprint for movement. Instead, each dancer interprets the cues through their own personal lens.

Participants highlighted the role of instructor feedback, including providing insights regarding the dancer's current performance, offering invitations to explore, and identifying areas for further development. For example, cues such as "Give me more or you're not giving enough and you're exploring this but I actually want you to explore this" (P5, Recognizing Value) and "Dive deeper with this idea" (P3, Recognizing Value) gently nudge dancers to explore. Dancers noted that these cues "push...you in the right direction. It's never offensive" (P2, Recognizing Value). Furthermore, some cues function as attentional beacons, illuminating the focus of the improvisational task as it is sometimes difficult for dancers to remember ideas and instructions in-the-moment–i.e., "Pay attention to shapes and angles" (Author Knowlton). Other cues incite dancers to transcend their comfort zones–i.e., "Make bold choices" (Author Knowlton). In essence, these instructional cues form an intricate support system to challenge dancers in their creative improvisation.

5.1.4 Self + Environment.

Visual Focus: Shifts in visual focus from body actions lead to inspiration and idea generation. Dancers highlighted how shifts in visual focus inspired them. Often, these shifts were triggered by body parts entering their line of sight: "My focus would change. I'd be making eye contact, and then if my hand would pass through my eyesight, then it would go to myself and then I'd copy the shapes of my hands and stuff like that" (P1, Focus). This dancer's consciousness shifted with her eyes' movement, embodying her focus.

Mirrors or reflective objects also influenced focus. They didn't just enhance self-awareness but also ignited inspiration. Dancers

utilized mirrors to discern shapes in their and their partners' forms, offering a fresh viewpoint: "looking in the mirror, you could see the outside of your body from a different perspective. So I would think that I look like one thing and then I would look in the mirror and see that I look completely different. So it was easier to find new angles on my body from just looking in the mirror" (P6, Focus). Another dancer used a window for reflection: "I feel like you can see them [the shapes] in a different way than when you're looking at yourself because you're looking at your reflection so you can see the outside of your body, but then I would turn away and also use the windows" (P5, Focus).

In participatory sense-making, this represents a change in coordination level, leading to altered participation within the interaction [38]. By focusing on a body part in a mirror or window, dancers transition from individual to orientational sense-making, integrating observed ideas. The environment, in essence, becomes a partner, prompting dancers to experience evolving sense-making levels.

Overthinking: Overthinking by consciously focusing on too many factors at once can disrupt the flow and spontaneity of the improvisation. During improvisation, not all choices are conscious. Overattending can lead to "overthinking" or "getting in [their] head," disrupting the natural flow of dance, a phenomenon known as the centipede's dilemma or Humphrey's Law [51, 83]. Conscious analysis can hinder creativity, resulting in a less dynamic performance. As expressed by a dancer, "The best thing is don't think about it. If you think about it then you'll probably won't be...natural" (P1, Movement Strategies).

This dilemma was evident when dancers were asked to consciously decide who was leading in the Leading/Following activity. Surprisingly, all pairs mirrored each other. Many felt the instruction made them "get in [their] head" (P3, Leading/Following). One dancer shared her overthinking process: "...I'm like, 'What if she's just giving me all this information and I just took inspiration from one thing and going in and then she's going to follow?' And I just put an emotional stance on it and I didn't want her to feel bad if I was not following her" (P1, Leading/Following).

Conversely, the best improvisations happened when dancers silenced their analytical minds, relying on trained instincts. This does not imply unawareness; it is a different kind of focus, more holistic and less analytical. In the Movement Strategies session, P5 mentioned she could only consciously focus on a few dance dimensions simultaneously: "I probably [attend to] like two of them all the time." Prompts might guide which aspects dancers consciously think about. However, discussions on mindfulness (5.1.6) suggest dancers attend to multiple factors simultaneously in an embodied manner.

5.1.5 Environment + Partner.

Sensory Communication: Dancers intentionally communicate with each other using a variety of somatic strategies, including touch, breath, and body movement sounds. Dancers utilize somatic strategies like heavy breathing, stomping, and limb noises for communication. P4 (Communication Techniques) noted, "I'm usually a very visual learner...But with this, sound was what helped the most...it was much easier when I could hear your breath or stomping." Observations confirmed dancers coordinating through auditory techniques, with some intensifying their breath and footfalls for rhythm. Initially, dancers leaned on visual cues. P1 (Communication Techniques) shared, "Breath for me really helped because for the first half I was watching a lot...For the second half, when I was using my breathing, we were both moving together when we were breathing together...both ways were beneficial in different ways." P1 highlighted the synergy of visual cues and synchronized breathing for understanding partner intentions and improvisation rhythm. As dancers became fatigued, their breath grew more pronounced, emphasizing the mind-body connection. P6 (Communication Techniques) reflected, "When you're using breath, it becomes more physical...The more exhausted you get, the more it comes out naturally." P6 also contrasted somatic strategies with verbal communication, stating, "I find myself using breath or sounds when I dance, but not words. It would be weird to me."

Expanded Eye Gaze: Dancers use expanded eye gaze–including peripheral vision, the mirror, watching each others' feet, and looking at each other's bodies–to foster awareness. Dancers utilized expanded eye gaze techniques, including peripheral vision and reflections in mirrors, to maintain partner awareness. Peripheral vision enabled dancers to adjust their movements based on their partner's actions without directly focusing on them. P3 (Interaction Dynamics) mentioned, "Just seeing peripherally what she was doing and how I could either match it or juxtapose it." They also emphasized observing the partner's body movements over facial cues, stating, "I think I was more focused on what her body was doing than looking at her." P3 (Communication Techniques) highlighted the importance of sensing and aligning energy, noting moments of synchronicity: "I feel like energy...there were points where we would kind of sync up even though we were both facing opposite ways, we would both kind of feel the energy of each other and slow down and sync up that way." Mirrors expanded dancers' perspectives, helping them gauge spatial factors. P4 (Interaction Dynamics) observed, "[the mirror let me] see her levels and things that I can't see from this close." Mirrors also enabled self-reflection and adjustment, allowing dancers to reconcile discrepancies between intended and actual movements.

5.1.6 Self + Partner + Environment.

Mindfulness: Dancers use presence and mindfulness to attend to their partner, their own sensations, and the environment. Dancers conveyed how their in-the-moment attention oscillated between their internal mental states, the movements of their partners, and the intricacies of their surroundings. As P1 described, "I noticed my focus was very parallel, I guess, not looking at the front and the back. It was very much partner, floor and ceiling. So I feel like my energy was very much this way towards my partner" (P1, Focus). This dynamic flux in attention was often driven by visual stimuli (5.1.4) or sounds (5.1.5).

Multiple dancers across sessions discussed the experience of 'feeling' their partner's energy or 'drawing' energy from their partner (P1, Focus; P2, P3, Communication Techniques; P9, Interaction Dynamics). For instance, one dancer described how she coordinated the mood of the improvisation with her partner: "I feel like, also,

you can feel somebody's essence. Because I have been in places that I literally have just met this person and she just gave me an energy and we both started going crazy and dancing very high energy..." (P1, Focus).

'Energy' is a complex term with multiple meanings, especially in the dance world. However, in some cases it seems like the dancers were referring to feeling the 'vibe' in the room or being closely attuned to their partner. This mutual awareness relates to the success of the improvisation (5.3.1). Cultivating this awareness requires carefully attending to multiple senses in-the-moment (5.1.5, 5.1.5).

Mind Wandering: Mind wandering or distraction during the session is common and can influence the interaction in a variety of ways. Multiple dancers referred to their minds wandering or getting distracted during the improvisation session. Mostly, they were referring to mind wandering within the dance space (e.g., getting distracted by something in the room), rather than completely off-topic thoughts (e.g., thinking about their homework or their next class). This relates to several other themes, such as Visual Focus, Self Focus, and Role of the Mirror.

Sources of distraction included features of the room (e.g., colors, objects, lines/angles), noises (e.g., echoing in the room, voices in the hallway), the mirror, and aspects of the dancers' bodies (e.g, texture of skin, shape of hand). Distractions sometimes served as sources of inspiration–for example, P1 took inspiration from her partner's body: "I was being inspired by the floor and all the lines and stuff on it and the ceiling, also the textures and then even the texture of my partner's skin and her hair and her toes at one point, just different things" (Focus). At other times, mind wandering pulled dancers' focus from their partnered collaboration, as P6 described: "I definitely strayed from the prompt I think when I was focusing more on myself, which is why I tried to focus on my partner a lot more...I would get distracted by the sounds that were in the room instead of what I was actually supposed to be doing" (Focus).

5.2 Generative Strategies

Generative strategies refer to tactics that dancers use to ideate and select actions to perform during the improvisation. The strategy that a dancer chooses to employ is impacted by both in-the-moment influences and heuristics for a successful collaboration.

5.2.1 Common generative strategies: Common strategies used to respond to movement include: mimicry, mirroring, repetition, translation, recognizing patterns, transformations, similarity and contrast, remembering, and augmentation. During the Movement Strategies focus group session, we asked each participant to tell us whether they used certain movement strategies *never*, *sometimes*, or *a lot*. The list of movement strategies we asked about are all strategies that *LuminAI* can utilize and are themselves drawn from theory on dance and improvisation [11, 38, 60, 88, 101]. They are described below.

- *Mirroring:* Performing the mirror image of your partner at the same time.
- *Mimicry:* Performing the exact movement as your partner at a later time.
- *Repetition:* Repeating a movement multiple times during an interaction.
- *Translation:* Transferring a motion to a different body part—e.g., P1 does something with their arm, then P2 does the same thing with their leg.
- *Patterns:* Repeating movement sequences.
- *Transformations:* Translating a movement according to a particular dimension (e.g., changing the speed or level of your partner's movement).
- *Similarity or contrast:* Responding with a movement that is similar or contrasting to your partner's movement.
- *Remembering:* Performing a previously learned gesture (e.g., something you tried last week in rehearsal).
- *Augmentation:* Repeating an observed gesture but adding something extra to it, like an extra arm movement.

Dancers corroborated that these are all strategies they use in practice (Figure 5). *Similarity and Contrast* was the most commonly used strategy. Dancers in other sessions also mentioned their use of these strategies—for example, P3 (Introducing New Ideas) discussed mimicking the movement of her partner's body parts ("So I think we started off with an arm sway and then that kind of just translated off into doing it with the legs. So it would just be the same movement, but different limb"); P2 (Communication Techniques) talked about finding contrast ("and then we were kind of contrasting. If he's up, I went down..."); P5 (Introducing New Ideas) mentioned transforming movements ("I think we just constantly pushed the time, space and energy of that movement. So quicker, bigger, smaller. Walk in a circle and do it, but it was always evolving in some type of way, but it was the same movement"); and P5 (Movement Strategies) discussed remembering past movements ("I do catch myself repurposing...[t]hings that I do in class").

5.2.2 In-The-Moment Choice-Making: Most movement choices are made in-the-moment, not consciously planned in advance. When asked about their response strategy during dance, participants universally echoed sentiments like "It just happened" or "I don't really know." They described their decisions as organic, stemming from a feeling or vibe, with phrases like "natural flow" (P5, Movement Strategies) and "it naturally just builds" (P3, Movement Strategies). This suggests that dancers' choices are spontaneous, with the underlying factors embodied and not always consciously discernible (5.1.4).

Only occasionally did participants mention planning. Such 'plans' were either very short-term or high-level; detailed premeditated plans were not made. P5 (Movement Strategies) mentioned brief planning based on body positioning: "I didn't really have time to think, but I had time to, 'Okay, well her body's placed there, so I'll just go here and her body's placed there, so I'll go there.'" Another dancer emphasized overarching intentions: "I feel like I have to go in with an intention. I just kind of have to put myself in a mindset, kind of a prompt...a prompt that I usually go...[is] just like going through a life, like just someone's lifespan. So that kind of like it gives me points where I can be slow and it gives me points where I can be high energy..." (P3, Introducing New Ideas). Instructors also provide prompts to shape intentions (5.1.3, 5.1.3).

In-the-moment decision-making, rather than premeditated planning, is emblematic of improvisation [23]. As highlighted in 5.1.4, dance improvisation often thrives when dancers balance analysis with presence to remain immersed in the their choices.

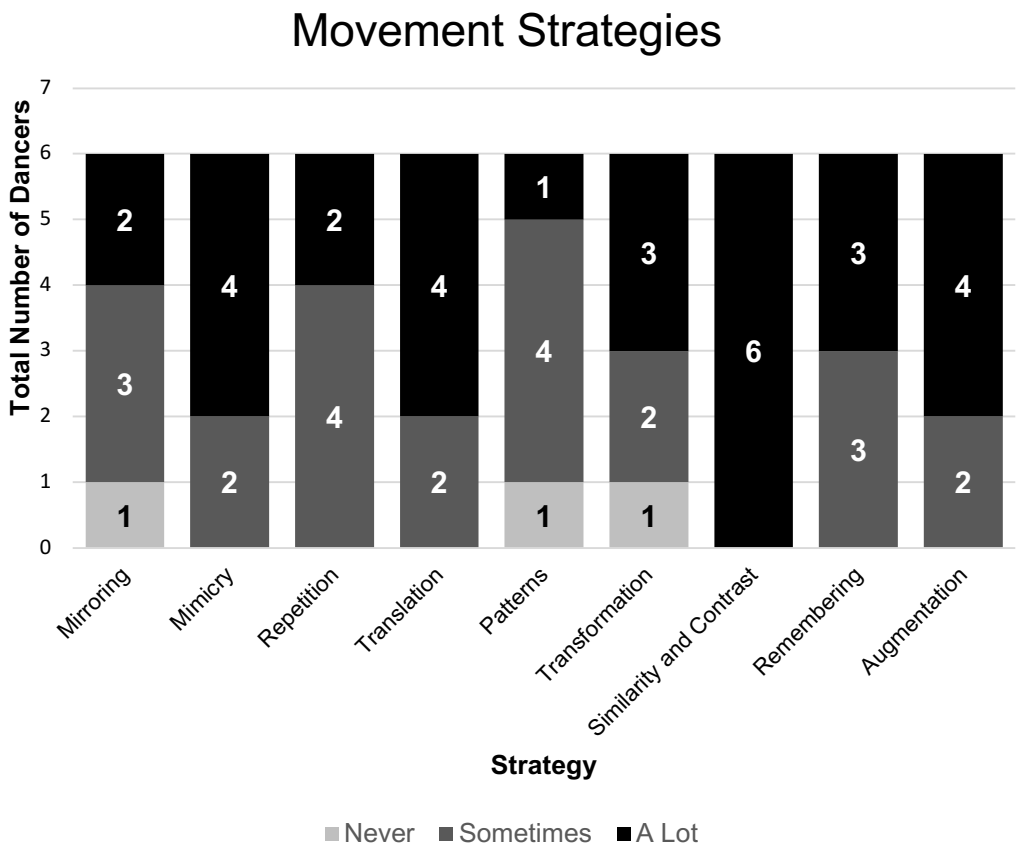

Figure 5: Graph showing the number of participants in the Movement Strategies focus group who said they used a movement strategy Never, Sometimes, or A Lot.

5.2.3 Motivation for Choices: A dancer's decision to utilize a specific response strategy may be influenced by: the current motif, exhausting their own ideas, and/or subtle movement cues from their partner. Dancers reported not consciously thinking about their movement choices and instead making decisions in-the-moment. However, dancers did mention a few stimuli that led to shifts in their movement choices. Dancers talked about running out of ideas and how boredom or repetition spurred transitions in generative strategies (5.1.2). Dancers also picked up on subtle movement cues from their partner as indicators that it may be time for a different type of response: "He also started to change like positions, like on where we were standing. Like I would start to go over here and then she'd like follow me" (P1, Movement Strategies). Finally, a few dancers discussed how their movement choices may be informed by the progression of a motif. For example, P3 (Introducing New Ideas) shared that her motif going into the interaction was "learning how to walk like a child" and elaborated that this was "something like that naturally builds. So I think you kind of have to know where you're going next because like, "Oh, I'm learning how to walk. What's the next step?."

5.2.4 Emergent Narrative: Narrative flows or crescendos can emerge through shared meaning-making in-the-moment. Several dancers described processes guiding their movement choices that indicated that a larger structure factored into their moment-to-moment decisions. As mentioned in 5.2.2, P3 (Introducing New Ideas) set an intention of moving through a person's lifespan to guide her improvisation. P2 and P4 (Introducing New Ideas) both described their interaction as a crescendo "I think it whatever we were doing slowed down and got smaller again. Like it would start smaller, whatever, like crescendo and then come back to here." Other dancers described an improvisation session as being like a conversation, "There's kind of like a beginning, like a topic of a conversation. And then there's kind of like, maybe there's like a joke made or something that kind of like builds upon. And then it's like, "Okay, conversation's done." Like, I feel like that's when the movement phrase is considered to be over, when your conversation is kind of finished" (P3, Movement Strategies).

These terms–*intention*, *conversation*, *crescendo*–convey a longer-term structure that loosely guides in-the-moment movement choices. However, this structure is more often related to rises and falls in energy than telling a prescriptive narrative with a distinct beginning, middle, and end.

5.2.5 Echo Strategies: Dancers demonstrate interest by using various ways of 'trying on' each others' movements (e.g., mimicking, repeating, transforming, incorporating a partner's movement into an existing motif). Many of the generative strategies used by the dancers (5.2.1) involved observing their partner's movement and incorporating it into their own body in some way–by mimicking or repeating or transforming it. These strategies are central to participatory sense-making, as they are part of *mutual incorporation*, or the process of 'trying on' your partner's gestures using your own body as a way of making sense of them [38]. Multiple dancers not only mentioned using these *echo strategies*, but also described the experience of exploring their partners' movements with their own bodies. This could look like a process of observing and repeating movements, as P3 (Recognizing Value) describes: "So like I found myself like just observing...So I was like taking what I could from what I observed from her and adding it into my own practice." It could also look like embodying a particular quality of movement (e.g., jerkiness), as P4 (Interaction Dynamics) described, "And just seeing like your movement quality and like picking up on the movement quality and then trying to put that on myself, to experience what she was experiencing," and P2 (Movement Strategies) echoed, "If I'm not mimicking like their actual movement, but I like to play with their speed. So like when she was like moving her foot, I would move it the same kind of speed with her..."

5.3 Heuristics

Heuristics for a successful collaboration refer to high-level guiding principles that determine whether an improvisation session is successful. These heuristics may influence in-the-moment choices as well as the generative strategies that are used.

5.3.1 Awareness of Each Other: A good collaborative dance improvisation represents a partnership where each dancer is spatially and temporally aware and incrementally builds on the partner's movements, rather than an offering of two discrete solos. Dancers deliberated on the qualities of an ideal improvisational partner. Central to a fruitful session is mutual awareness, both spatially and temporally. This hinges on each dancer's ability to discern, adapt to, and expand upon their partner's movements. Such awareness ensures dancers don't eclipse each other, promotes connection, and encourages a natural exchange of ideas. Spatial cognizance is paramount; it not only prevents collisions but also lets dancers exploit dynamics like positive and negative space. P1 (Recognizing Value) emphasized the importance of patience in building mutual understanding: "[a good partner]... takes the time to observe your movements and finds space. Whether that's between you, beside you to really think through each step and like just taking time slow at first helps."

In specific scenarios, like contact improvisation, mutual awareness becomes even more crucial. Sharing weight requires heightened awareness to ensure safety, as negligence can result in accidents. P5 (Recognizing Value) stated, "there's kind of that responsibility to be hyper aware of your partner so that you're able to take weight and help move their body, because if something were to go bad, someone's going to get injured."

A challenge in improvisational dance is avoiding unintentional parallel solos, emphasizing the need for active connection. P2 (Recognizing Value) reflected, "I guess for me it kind of more so felt like two solos rather than it being like a partnering type thing and like having that connection and just kind of felt like I was there and they were there and we were just dancing in the same space."

5.3.2 Emphasis on Connection: There is an emphasis on the process of building connection, emotion, and feelings amongst partners rather than technical success of individual executed movements. Dance improvisation is anchored in the lived experience of movement rather than its external display. The true connection emerges when dancers emphasize the emotional and kinesthetic sensation of the dance, creating a mutual, deeply-felt journey rather than just performing technically challenging or visually striking movements. P2 (Recognizing Value) noted, "It's mostly how it feels rather than how it looks. I find that the best improv partners or the best session isn't really about how we're looking or how the dance movement is. It's more so about how we're connecting and rather how we're feeling instead of how it looks on the outside."

The heart of successful improvisation lies in the felt experience over choreographic depiction. P3 (Recognizing Value) shared, "I've had kind of an idea or a motif, like going into it and just exploring that without thinking of it as like dancing so much, but more so just exploring an idea and seeing what that feels like." At times, dancers achieve such a deep bond that they become immersed in their experience. P3 (Recognizing Value) elaborated, "I think that anytime that I've ever been with a partner and I find myself forgetting that I'm in a room full of other people too, just getting lost, kind of sharing the eye contact, sharing that moment...you feel like you are the only two people like in the room I feel like is a very special thing."

While in set choreography, dancers are trained present their most polished movements through practiced sequences, improvisation demands a shift. It beckons dancers to inhabit the present, valuing genuine, spontaneous freedom of expression over practiced flawlessness, enabling them to "just move" (P2, Recognizing Value).

5.3.3 Mindset Shapes Perception: The perception of movement and its effectiveness is influenced by mindset. A movement in improvisation derives its value not from technical difficulty but from the emotional weight assigned to it by the dancer. Thus, even ostensibly simple movements can be imbued with deep meaning and emotion when approached with the right mindset. As P3 stated, "That's a mindset thing for sure. I don't think any particular type of movement is quote unquote good until you make it good, because even if something is not...It doesn't look the best. If you say in your head like, 'Oh, but that was good because of this, this and this.' Then you kind of make it good with your own mindset" (P3, Recognizing Value).

5.3.4 Seeking Equality: Dancers were concerned about equal turn-taking and paying attention to what their partner offered. Throughout the sessions, dancers emphasized their attentiveness to their partner's emotions, aiming for an equal partnership through turn-taking and observing each other's movements. This was particularly evident in the Leading/Following session where they were prompted to consciously discern leadership roles (5.1.4).

When one partner feels overly observed, it disrupts the balance. P3 (Recognizing Value) stated, "I think also it puts a lot of pressure on the one partner if you're feeling like you're being observed a lot...

but then also coming back to like the eye contact and the connection at times." A genuine partnership allows both dancers to introduce their unique ideas, avoiding a one-sided narrative. P4 (Recognizing Value) mentioned, "I feel like sometimes if...your partners make their own type of choices and kind of just follow completely what you do, it's harder to combine your different ideas."

Physical aspects, like weight sharing, pose challenges in maintaining equality. It's vital to interact respectfully, not imposing too much on the partner or making decisions that might jeopardize their comfort, as P1 (Recognizing Value) noted.

5.3.5 Shared Language: To understand how to improvise together, dancers need to develop the ability to transfer elements of dance structure such as time, space, effort, body, energy, and rhythm. Through years of training, dancers develop an understanding of foundational dance elements like time, space, effort, body, energy, and rhythm which they use to guide a successful improvisation session. This amounts to a domain language that is shared even amongst dancers who have never previously met. This language allows dancers to continuously explore a movement phrase in terms of its spatial dimensions, timing, and energy levels. While the core movement remains recognizable, its unfolding captures the essence of improvisation, "It was like consistent movements, but like blossoming into bigger and different tempos" (P1, Introducing New Ideas). A shared language between dancers allows them to take a familiar movement and present it with a unique twist, building off of each other. Using this language, the "same type of movement" can be experienced and displayed in a "different way" (P1, Movement Strategies).

6 DISCUSSION

In this section, we first identify design recommendations for *LuminAI* based on our findings. These can additionally inform other researchers working on designing embodied improvisational agents or technology for dancers. Then, we reflect on challenges and opportunities our findings present for HCI in embodied improvisational domains.

6.1 Design Recommendations for LuminAI

6.1.1 Account for Human Needs & Emotions to Establish a Relationship.

- *Design Recommendation: The AI improviser should account for their partner's bodily sensations and emotions to calibrate movement choices and build trust.*
- *Related Themes: Emotion, Bodily Sensation, Prior Relationships, Awareness of Each Other*

From a pragmatic perspective, it is important for an AI improviser to factor in risk and safety for their human partner when choosing movements. In addition, establishing a common ground regarding the mood and level of challenge can improve the collaboration and foster trust between the human and AI partner. Awareness and consent are particularly critical when touch and weight sharing is involved.

We are considering implementing an on-boarding experience for dancers interacting with *LuminAI*. For example, if a dancer stated that her knee was sore during an introductory session, the agent could avoid movements involving jumping, leaping, or the floor. Personalized machine learning models could allow dancers to switch between data sets trained for different moods or levels of challenge. Including a warm-up period could also help to ease the dancer into the interaction and warm up their bodies.

Trust and consent were identified by participants as key to building a relationship with a dance partner. Prior literature on pair improvisation indicates that trust is built temporally [22]. Allowing for avatar customization in *LuminAI* could result in a visually familiar partner. In addition, implementing user profiles would allow *LuminAI* to build trust, empathy, and shared memories with a partner. These efforts could be informed by recent HCI research on fostering human-AI trust (e.g., [117]).

Dance improvisation is an affective and cognitive experience that occurs within and is expressed through bodily movement [96]. Designers might consider linking experiential concepts of Körper (physical body) and Leib (feelings and sensations), as discussed in Mueller et al. [79], to monitor the relationship between dancers' emotions and their movement experiences with *LuminAI*. This can be achieved by asking dancers to rate their improvisation sessions using tools like a smileyometer [79], or to evaluate specific aspects of movement and sensation from both human and agent perspectives. By aggregating data on topics like feeling 'great' or 'tired', and correlating it with quantitative Körper data we can understand the emotional impact of specific movement sessions.

Designers can consider various quantitative Körper data to correlate with sensation. This includes tracking movement frequency to gauge activity level, measuring spatial extent to understand space utilization, and monitoring speed and acceleration for insights into movement intensity. Additionally, analyzing the complexity of movements can reveal cognitive and emotional engagement, while exploring the relationship between music and emotional expression offers clues about the depth and range of human affective experiences. Engaging different body parts in the dance and estimating energy expenditure can further indicate emotional intensity. These metrics, quantified using motion sensing technologies as well as smart watches, can then be correlated with dancers' self-reported emotional experiences, providing a comprehensive view of the emotional dimensions of movement.

6.1.2 Multi-Sensory Input for Increased Agent Presence.

- *Design Recommendation: AI systems should be equipped with a variety of tools for sensing and interacting with their partner and the environment to increase agent presence.*
- *Related Themes: Communication, Inspiration from World, Mind Wandering, Focus*

LuminAI currently can only observe the human body moving through space. It cannot detect aspects of the body such as breath, eye contact, or sound. Augmenting *LuminAI* with sensors could enhance its ability to collaborate with a human partner in real-time. In addition, dancers attend to elements of the environment, such as lighting, temperature, or patterns. Enabling *LuminAI* to take inspiration from a photo, 3D scan, audio recording, or temperature sensor could lead to more novel and relevant movement choices. Finally, *LuminAI* is not able to express itself using many of the strategies identified by dancers. A key challenge to expanding modes of expression is avoiding the uncanny valley effect—for instance, adding eyes that track the dancer may be more creepy

than communicative [57]. We are exploring how respiration and orientation could be used to communicate. Prior work supports the notion of utilizing breath and sound for coordination purposes [119]. Vass-Rhee [119] notes how dancers and choreographers often explore diverse methods to synchronize movements, either in the absence or presence of a regular beat or rhythm. They might utilize cues from breathing, background noises, or single or multiple syllable sounds to structure their choreographies in collaboration with other dancers.

6.1.3 Customized Constraints to Spur Focused Exploration.

- *Design Recommendation: Design systems that allow dancers and instructors to set constraints or prompts to spur focused exploration of a particular theme.*
- *Related Themes: Instructor Cues, Overthinking, Structured vs. Unstructured Improvisation*

Dancers can only consciously focus on a few qualities of movement at one time. Prompts and cues help center an improvisational session on a common theme. An AI partner should be able to take a prompt (e.g., focus on shapes and angles) at the outset of the session or receive a cue (e.g., incorporate all levels, utilize spacing, or explore other body parts) mid-session and shape its movement choices accordingly. This is supported by prior literature on the importance of constraints in improvisation [110].

LuminAI currently facilitates some customization by allowing the user to select different movement response strategies using a dropdown menu. This could be expanded to allow dancers to more closely customize the experience. This could be a hands-free interface, where a dancer or instructor could speak a prompt and that would be translated into a set of constraints for the agent.

6.1.4 Focus on Action Sequences, not Discrete Movements.

- *Design Recommendation: Reconsider measures of value and consider designing to support reasoning about longer sequences of full body actions rather than discrete movements.*
- *Related Themes: Continuous Motion, Emergent Narrative, Emphasis on Connection*

Value in movement improvisation arises from the connection with one's partner rather than technical execution or novelty–a finding that contrasts with existing models for evaluating creative outputs in HCI research [39]. Therefore, designers of embodied co-creative AI should consider measuring value at a session-level rather than at individual movement level. Techniques such as retrospective questions or live emotion tracking for dancers could provide insight into the caliber of the human-AI collaboration. This approach is supported by literature which highlights how sequences of known gestures can result in an emergent novel output [10, 18, 33, 55] and that "creativity in composing dance lies as much in sequencing, melding and linking the parts of the work, as in the creation of the parts themselves" [108].

In addition to rethinking value, designers should consider how AI can detect and engage in emergent narrative flows in dance. An AI dancer should not merely respond to isolated body actions. Instead, it should discern the broader context of the improvisation and pick up on patterns and shifts in energy. This requires the development of an agent that can reason about sequences of gestures, not just discrete movements. Mapping patterns and sequences of generative strategies used by dancers could expand the agent's reasoning to a more continuous understanding of movement–for instance, the ability to recognize and respond to the progression of a motif or observe that mimicry is often followed by subtle transformations.

6.1.5 Rethinking the Body and "Gesture".

- *Design Recommendation: Reconsider how to represent the body and gestures given the continuous nature of improvisation.*
- *Related Themes: Shared Language, Motion*

Earlier versions of *LuminAI* represented the body as a series of joint positions and segmented discrete gestures to reason about using moments of stillness, or shifts in rhythm to break up continuous motion data. In light of our findings about the continuous nature of improvisational movement, we are rethinking and operationalizing the term "gesture" and how we represent the body in *LuminAI* using LMA [60]. Prior work has formalized Laban Efforts which are primarily used to describe the quality of movements, i.e., 'how' movements are performed [35]. However, there is a lack of formalized vocabulary aimed at detailing observable movements and establishing a structured language to define 'what' they are doing in a tangible way. Let's unpack this. LMA defines movement as *body actions*. These body actions can be of two different types: *postural body actions*, which indicate full-body movements and *gestural body actions*, indicating a singular body-part. To take into consideration elements of shared improvisational language, we need to construct a body action taxonomy that segments movements into postural full body actions instead of singular gestural body parts. For example, a full body action can be broken down into several descriptors: whether it is stationary, turning, traveling, etc.; what intentional upper/lower body limbs it uses for expression; the position and alignment of the body in space; and the primary segment for bearing weight. By creating and applying this taxonomy to classify body actions, we initiate a process of more objectively describing an individual's movement, advancing towards a unified approach characterizing movement across different domains.This shapes our current working research on *LuminAI*.

6.1.6 Use Echo Strategies to Foster Trust and Elaborate on Ideas.

- *Design Recommendation: AI agents can foster mutual trust and elaborate on ideas using echo strategies such as mimicry, transformation, and repetition.*
- *Related Themes: Echo Strategies, Awareness of Each Other, Common Generative Strategies, Motivation for Choices, Seeking Equality*

Dancers commonly use *echo strategies* such as mimicking, transforming, or repeating a partner's move in order to show they are attending to their partner and to jointly explore an idea. This validates the existing response strategies *LuminAI* uses, which were developed based on literature on participatory sense-making [38], improvisation [88, 100], and dance [11, 60]. Prioritizing moments for *LuminAI* to echo its human partner, coupled with visual or auditory cues to indicate attention, could build trust and increase feelings of equality. In addition, the agent can use echo strategies to elaborate on a motif.

6.1.7 Use Avatar Design as a Tool for Communication.

- *Design Recommendation: Avatar design can be leveraged as a tool for communication and inspiration.*
- Related Themes: Mind Wandering, Echo Strategies, Sensory Communication, Emphasis on Connection, Instructor Cues, Emergent Narrative

Dancers mentioned taking inspiration from the textures of their partner's body. This could present interesting opportunities for the design of the AI avatar in both rehearsal and performance, as the colors and textures of the avatar's 'skin' could be altered to shift the tone of the performance (e.g., a spiky skin could spur sharper movements). The AI avatar also does not have to be completely humanoid, so options for alternative bodies could be explored. For instance, if an instructor cue in rehearsal prompts dancers to 'act like water,' the AI avatar could transform into a more fluid body.

In addition, dynamic avatar design could be utilized as a tool for communicating with the human dancer, with colors, textures, or animations indicating moments of connection, rises and falls in energy, or attentiveness, drawing on prior work [92]. Since *LuminAI* is a projection and not an embodied being, avatar design could provide necessary additional sensory dimension for communication. Finally, avatar design could also be an avenue for personalization and building trust, as noted in 6.1.1.

6.1.8 *Slowing and Repeating to Shift Motifs.*

- *Design Recommendation: Detecting repetition or moments of slowing down could indicate a shift in motifs.*
- *Related Themes: Shifting Bodily Cues, Eye Contact, Mutual Touch Communication*

Dancers often communicated completion of a motif with slower movements, reduced energy, or repetition of a movement. In contrast, moments of flow were often indicated by touch, eye contact, elaboration, and heightened energy. Others have studied how to detect flow states in various contexts via EEG sensors [123], key strokes [62], and observed emotions [12], but there is little prior work on what flow looks like in dance. In future versions of *LuminAI*, the agent could anticipate shifts in motifs by detecting moments of stillness, slower energy, or repetition, and respond by introducing a new motif. Similarly, recognizing moments of eye contact or synchronized movement could indicate a period of elaboration and joint sense-making.

6.1.9 *Use Mirrors with Caution.*

- *Design Recommendation: Carefully consider when to represent a dancer's reflection, as mirrors can easily become a crutch or a distraction from the collaborative session.*
- *Related Themes: Self-Focus, Role of the Mirror*

Our findings indicate that mirror use may draw focus from the collaboration. Previous research on the use of mirrors in dance improvisation suggests that their use should be limited until dancers have developed sufficient improvisational skills. This is because mirrors can induce self-consciousness and banality, leading dancers to focus on appearance rather than authentic expression, thus eroding self-belief and promoting an excessive preoccupation with self-image [82].

Additionally, using mirrors to observe others can lead to constant comparison, which may drain energy and disrupt the delicate balance of one's creative imagination, thereby making it difficult to regain the original rhythm and flow of improvisation [82]. Prior work by Radell et al. [89] posited that mirrors serve as a distraction that prevents dancers from focusing on their kinesthetic awareness. We have previously used live projections to present dancers with their motion capture data alongside the AI dance parter [65], but this self reflection may be distracting. Designers should consider using facial recognition to track the number of times dancers look at the mirror (or any other 'reflection' of their body). Reflections could be turned off or covered if the dancer seems distracted. We are considering implementing a playback feature to allow dancers to reflect on their movements while maintaining continuous focus in-the-moment.

6.1.10 *Center Presence and Mindfulness.*

- *Design Recommendation: Identifying ways to center presence and mindfulness can improve the success of the human-AI improvisation.*
- *Related Themes: Mindfulness, Awareness of Each Other, Mind Wandering*

A key theme that dancers kept returning to was the idea of being present in the moment and mindful of their partner and surroundings. *LuminAI* should therefore demonstrate that it is observing, syncing up with, and building off of its human partner's movements, and the agent should avoid extended periods of movements that are not clearly related to its partner's movements. *LuminAI* could also detect when a human dancer is getting 'too internal' and not responding to the AI dancer's movements. A visual or auditory prompt could remind the dancer to engage more with their partner.

Designers could consider incorporating visual feedback in the negative space, such as background color changes or visualizations, to reflect different engagement levels. Additionally, haptic feedback could be used to emphasize specific aspects of the experience. To reduce mind wandering and enhance mindfulness, designers could integrate visualizations of breath awareness. This approach is supported by research from Levinson et al. [63], which found that breath awareness training reduces mind wandering and increases meta-awareness, thereby enhancing awareness of inner experiences. Further, studies on mindfulness indicate a link between training in inner awareness and improved outer awareness [8]. This suggests that in interactive mindfulness programs, it might not be necessary to focus exclusively on outer awareness if inner awareness practices are included. Designers can also use breath data, such as inhales and exhales, for interactive elements. This can be presented as breath count summaries or wave visualizations to indicate changes, as explored in [21].

Prior research has explored how to use 'vibe' to moderate user experiences with technology [37], and researchers in the virtual reality (VR) community in particular have explored how to foster feelings of presence [102]—this could be an area of work to draw upon in the future. *LuminAI* could guide the human dancer to enter a mindful state or introduce a vibe for the joint session. We could also foster presence with a more immersive experience using sound and light.

6.2 Challenges and Opportunities for HCI Design for Embodied Co-Creative AI

In this section, we think beyond the design of *LuminAI* and reflect on the challenges and opportunities our findings present more broadly for HCI in embodied improvisational domains as summarized in Table 2. We envision an interdisciplinary future research agenda that incorporates expertise in AI and machine learning, robotics, affective computing, embodied interaction, and human-centered design.

Modeling Unpredictability in Co-Creative AI Systems: Our findings presented an interconnected model of improvisational dance inputs, connecting in-the-moment influences represented by the self, partner, and environment as well as generative strategies and heuristics that shape improvisation. A significant challenge for designing improvisational co-creative AI systems is the inherent unpredictability in human behavior, particularly for creative motor activities [110]. Given that personal, environmental, and task constraints fluctuate stochastically, AI systems need to be able to adapt to these random variations in real-time [5].

Torrents et al. [110] talks about how this requires not only understanding deterministic influences, like specific invitations or solicitations to act, but also navigating the stochastic nature of human behavior, which includes random fluctuations and 'noise'. Deterministic influences encompass predictable and consistent factors such as structured prompts, pre-programmed scenarios, specific rules or constraints, environmental triggers, predictable emotional responses to stimuli, feedback loops, and established patterns of physical interaction. These influences lead to expected outcomes and behaviors. On the other hand, stochastic influences introduce unpredictability and variability, characterized by factors like human emotional variability, spontaneous creative decisions, unpredictable environmental changes, random technical fluctuations, fluctuations in user attention and fatigue, dynamic social interactions in group settings, improvisational dialogue responses, sensor noise and data variability, contextual ambiguity, and external interruptions. Together, these deterministic and stochastic elements create a complex tapestry of interactions in human-AI systems, balancing predictability with the unpredictable nature of real-world scenarios.

The challenge is in creating AI systems that can effectively model and respond to unpredictability, mirroring the dynamic and spontaneous nature of human improvisation. Addressing this challenge opens up the opportunity to design AI systems that can enhance the creative process through adaptive and dynamic interactions. Such systems would not only respond to predictable patterns of human behavior but also thrive in the face of variability, leading to more authentic and engaging co-creative experiences. This can lead to breakthroughs in fields like performative arts, therapeutic practices, and educational tools, where improvisation plays a key role. By successfully modeling unpredictability, AI systems can provide a more realistic and human-like collaborative experience, pushing the boundaries of what is possible in human-AI collaboration and fostering a deeper level of creative expression. Towards this effort, in our current work we are developing a framework of knowledge needed for improvisational AI systems in unpredictable environments [70].

Understanding and Representing Non-Verbal Emotional Intelligence in AI: Designing embodied AI systems capable of understanding and responding appropriately to human emotions in real-time is a significant technological challenge that requires insights from psychology and human behavior. This complexity arises because emotions in creative motor behavior are often communicated subtly through facial expressions, expressive body language, or changes in body posture [58]. Auditory cues such as breath have been traditionally overlooked but recently valued as an important aspect of dance [106], confirmed by our findings. The challenge for AI in interpreting and responding to non-verbal cues like body language, breath, and facial expressions lies in the need for sophisticated sensory and processing capabilities. Developing these sensory capabilities, combined with human-centered design strategies, is essential to avoid creating agents that might elicit unsettling or uncanny perceptions [78].

To explore the use of respiration for coordination or communication, we conducted a preliminary study on capturing breath patterns—inhales, exhales, silence, and noise—during dance. Our model distinguished breath sounds with only 50% to 60% accuracy due to a limited and noisy dataset, challenges in accurate labeling, and sub optimal recording conditions. Fisahn et al. [36] discuss the complexities in measuring respiratory parameters such as low tidal volumes and high breathing frequency, especially in motion, underscoring the necessity for non-intrusive yet precise methods for assessing respiration in dynamic contexts.

Responding to Changes in Contextual and Environmental Cues: Our findings corroborate the idea that embodiment involves being situated in a complex physical and social space [32]. AI must become adept at understanding and responding to environmental cues. This includes responding to changes in the environment, like lighting, temperature, or humidity, which can impact creative settings [106]. An opportunity to draw on prior work in ubiquitous computing [34] and integrate cross-modal sensory data to enable AI to respond to environmental and non-visual cues could revolutionize the experience, including providing opportunities for remote improvisational collaboration.

Reconceptualizing Body Representations: Existing joints-based representations of the body common in motion capture ignore many aspects of the bodily experience, including somatic feelings such as pain or pressure, soft tissue movement, and the ways in which bodies shift and change over time. Reconceptualizing how we represent bodies in embodied interaction design is a key challenge for HCI [107]. Designers can innovate embodied interaction design by developing more holistic body representation systems. These systems could integrate somatic experiences and the nuances of soft tissue dynamics, leading to more accurate, empathetic, and creative understandings of human movement and experiences in digital environments.

Translating Physical Interactions: The study underscores the importance of physical interaction (like touch and weight sharing) in dance. Translating this into HCI contexts where AI needs to interact physically with humans poses challenges in terms of safety, appropriateness, and comfort. An opportunity opens to extend the design of digital embodied agents towards hybrid models that include physical representations through the use of robots or objects

Table 2: Challenges and Opportunities for HCI Design

Challenges	Opportunities
Modeling unpredictability in co-creative systems.	Enhancing creativity and adaptive interaction.
Understanding and representing non-verbal emotional intelligence in AI.	Enhancing user experience by creating more empathetic and responsive AI systems as a result of improved affective computing.
Responding to changes in contextual and environmental cues.	Enabling cross-modal sensory integration to provide a more immersive and responsive interaction.
Reconceptualizing body representations.	Developing holistic body systems integrating somatic experiences and the nuances of soft tissue dynamics.
Translating physical interactions such as touch and weight sharing.	Expanding the scope of digital embodied agents to hybrid models utilizing robots or interactive objects.
Evaluating creative AI.	Identifying new metrics for success in co-creative AI.

as secondary forms of interaction. Current research in human-robot interaction [4] and biofeedback [116] can inform future work.

Evaluating Creative AI: Existing methods of evaluating creative AI focus on technical benchmarks [41], generated artifacts [39], or on users' feelings of creativity and immersion [20, 54]. Our findings indicate that other metrics may be necessary for evaluating the success of co-creative AI in embodied improvisational domains. These metrics would consider aspects like feelings of connectedness and mutual awareness, providing a more comprehensive assessment of AI's success in collaborative and improvisational settings. Such an approach could lead to a deeper understanding of the efficacy and impact of AI in creative collaborations.

7 LIMITATIONS AND FUTURE WORK

This study was conducted with 24 dance students at one university. Although a variety of body types, genders, and races/ethnicities were represented in our study group, it is likely that some perspectives were missed. Expansion on these initial results will be necessary in the future with dancers trained in different styles and cultural contexts, with different levels of expertise, and with different body types. In particular, our findings demonstrate the need for an expanded conception of 'the body' and bodily experiences in computational representations and communication. This corroborates calls to recognize and design for a plurality of bodies, and necessitates a future HCI research agenda that prioritizes understanding and designing for/with those with non-normative bodies [107]. For instance, we are exploring future work that investigates the role devices used by disabled dancers (e.g., wheelchair users) play in shaping embodied communication and collaboration.

Our design recommendations are derived from our findings, but have not yet been empirically tested through implementation in *LuminAI* and evaluation with dancers. We are concurrently: 1) developing a body action taxonomy to more accurately represent the full body actions of improvisational movements; 2) prototyping our design recommendations with dancers and instructors; and 3) onducting a longitudinal study to evaluate *LuminAI*'s impact on improvisational dance classes practices and performance rehearsals.

Finally, it is possible that dancers' expectations of an AI dance partner may differ from their expectations of a human dance partner. As we further develop *LuminAI*, our future work will investigate whether a human-AI interaction context necessitates alterations to our model of improvisational dance.

8 CONCLUSION

Co-creativity remains an under-explored area in HCI, particularly within embodied domains like dance improvisation. This paper takes a human-centered approach to developing AI [97], delving into the nuances of embodied human co-creativity to inform the design of co-creative AI systems. Through focus groups with dance students, we uncovered the intricate dynamics of dyadic interaction in movement improvisation, highlighting the delicate balance between self, partner, and environment. Our findings culminate in a comprehensive model that not only captures the multifaceted constructs of inputs but also offers generative strategies and heuristics for successful collaborative improvisation. This model can guide and inspire the design of future technologies in embodied movement improvisation.

In the context of our own work, as we highlight in the Discussion, our findings pave the way for the human-centered re-design of *LuminAI*, a co-creative AI dance partner. By understanding the core elements of human movement improvisation, we can inform the design of AI systems that can seamlessly co-create with us in embodied domains. While this paper focused on dance, the implications extend to a broader range of co-creative interactions, setting the stage for a future where humans and machines can collaboratively engage in real-time, embodied creative partnerships.

ACKNOWLEDGMENTS

We would like to thank Cassandra Naomi for her help running the focus groups and development work on *LuminAI*; Morgan Duvall for her help in data synthesis as well as Kennesaw State University's Department of Dance. This project is funded by the National Science Foundation (CMII 2123597).

REFERENCES

[1] Ann Cooper Albright. 2015. Split Intimacies: Corporeality in Contemporary Theater and Dance. (2015).
[2] Ann Cooper Albright and David Gere. 2003. *Taken by surprise: A dance improvisation reader.* Wesleyan University Press.
[3] Miquel Alfaras, Vasiliki Tsaknaki, Pedro Sanches, Charles Windlin, Muhammad Umair, Corina Sas, and Kristina Höök. 2020. From biodata to somadata. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems.* 1–14.
[4] Rebecca Andreasson, Beatrice Alenljung, Erik Billing, and Robert Lowe. 2018. Affective touch in human–robot interaction: conveying emotion to the Nao robot. *International Journal of Social Robotics* 10 (2018), 473–491.
[5] Natàlia Balagué, Rafel Pol, Carlota Torrents, Angel Ric, and Robert Hristovski. 2019. On the relatedness and nestedness of constraints. *Sports medicine-open* 5,

1 (2019), 1–10.
[6] Roger E Beaty. 2015. The neuroscience of musical improvisation. *Neuroscience & Biobehavioral Reviews* 51 (2015), 108–117.
[7] Tanya Berg. 2020. Manifestations of surveillance in private sector dance education: the implicit challenges of integrating technology. *Research in Dance Education* 21, 2 (2020), 135–152.
[8] Claudia Bergomi, Wolfgang Tschacher, and Zeno Kupper. 2014. Konstruktion und erste Validierung eines Fragebogens zur umfassenden Erfassung von Achtsamkeit. *Diagnostica* (2014).
[9] John A Biles. 1994. GenJam: A genetic algorithm for generating jazz solos. In *ICMC*, Vol. 94. 131–137.
[10] Lynne Anne Blom and L Tarin Chaplin. 1988. *The moment of movement: Dance improvisation*. University of Pittsburgh Pre.
[11] Anne Bogart and Tina Landau. 2004. *The Viewpoints Book: A Practical Guide to Viewpoints and Composition*. Theatre Communications Group, New York : St. Paul, MN.
[12] Joceran Borderie and Nicolas Michinov. 2016. Identifying flow in video games: towards a new observation-based method. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)* 8, 3 (2016), 19–38.
[13] John D Bransford, Ann L Brown, Rodney R Cocking, et al. 2000. *How people learn*. Vol. 11. Washington, DC: National academy press.
[14] Virginia Braun and Victoria Clarke. 2021. One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative research in psychology* 18, 3 (2021), 328–352. Publisher: Taylor & Francis.
[15] Derrick D Brown and Ruud GJ Meulenbroek. 2022. A systematic review of individual differences in perception, action, and decision making: Implications for dance education. *Journal of Dance Medicine & Science* 26, 2 (2022), 114–124.
[16] Jonathan Burrows. 2010. *Choreographer's Handbook*. Routledge.
[17] Francesco Cafaro, Alessandro Panella, Leilah Lyons, Jessica Roberts, and Josh Radinsky. 2013. I see you there! Developing identity-preserving embodied interaction for museum exhibits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1911–1920.
[18] Curtis L Carter. 2000. Improvisation in dance. *The Journal of Aesthetics and Art Criticism* 58, 2 (2000), 181–190.
[19] Charles S Carver and Michael F Scheier. 1978. Self-focusing effects of dispositional self-consciousness, mirror presence, and audience presence. *Journal of personality and social psychology* 36, 3 (1978), 324.
[20] Erin Cherry and Celine Latulipe. 2014. Quantifying the creativity support of digital tools through the creativity support index. *ACM Transactions on Computer-Human Interaction (TOCHI)* 21, 4 (2014), 1–25.
[21] Luca Chittaro and Riccardo Sioni. 2014. Evaluating mobile apps for breathing training: The effectiveness of visualization. *Computers in Human Behavior* 40 (2014), 56–63.
[22] Carlos Cornejo, Esteban Hurtado, Zamara Cuadros, Alejandra Torres-Araneda, Javiera Paredes, Himmbler Olivares, David Carré, and Juan P Robledo. 2018. Dynamics of simultaneous and imitative bodily coordination in trust and distrust. *Frontiers in psychology* 9 (2018), 1546.
[23] Richard Courtney. 1973. Theater and spontaneity. *The Journal of Aesthetics and Art Criticism* 32, 1 (1973), 79–88.
[24] Mihaly Csikszentmihalyi, Sami Abuhamdeh, and Jeanne Nakamura. 2005. Flow. *Handbook of competence and motivation* (2005), 598–608.
[25] Nicholas Davis, Margeaux Comerford, Mikhail Jacob, Chih-Pin Hsiao, and Brian Magerko. 2015. An enactive characterization of pretend play. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*. ACM, 275–284.
[26] Nicholas Davis, Chih-PIn Hsiao, Kunwar Yashraj Singh, Lisa Li, and Brian Magerko. 2016. Empirically studying participatory sense-making in abstract drawing with a co-creative cognitive agent. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*. ACM, 196–207.
[27] Hanne De Jaegher and Ezequiel Di Paolo. 2007. Participatory sense-making: An enactive approach to social cognition. *Phenomenology and the cognitive sciences* 6 (2007), 485–507.
[28] Karen Dearborn and Rachael Ross. 2006. Dance learning and the mirror: comparison study of dance phrase learning with and without mirrors. *Journal of Dance Education* 6, 4 (2006), 109–115.
[29] Manoj Deshpande and Brian Magerko. 2021. Drawcto: A Multi-Agent Co-Creative AI for Collaborative Non-Representational Art. In *Joint Proceedings of the AIIDE 2021 Workshops (CEUR Workshop Proceedings, Vol. 3217)*, Brent Harrison (Ed.). CEUR, Virtual Event, Lexington. https://ceur-ws.org/Vol-3217/#paper7 ISSN: 1613-0073.
[30] Xinyu Dou, Lin Jia, and Jinchuan Ge. 2021. Improvisational dance-based psychological training of college students' dance improvement. *Frontiers in Psychology* 12 (2021), 663223.
[31] Paul Dourish. 2001. *Where the action is: the foundations of embodied interaction*. MIT press.
[32] Paul Dourish. 2004. *Where the action is: the foundations of embodied interaction*. MIT press.
[33] Annerose Engel and Peter E Keller. 2011. The perception of musical spontaneity in improvised and imitated jazz performances. *Frontiers in psychology* 2 (2011), 83.
[34] Irfan A Essa. 2000. Ubiquitous sensing for smart and aware environments. *IEEE personal communications* 7, 5 (2000), 47–49.
[35] Sarah Fdili Alaoui, Jules Françoise, Thecla Schiphorst, Karen Studd, and Frédéric Bevilacqua. 2017. Seeing, Sensing and Recognizing Laban Movement Qualities. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 4009–4020.
[36] Sven Fisahn, Christian Siebauer, Jan Ringkamp, Kirsten J Dehning, Stefan Zimmermann, and Jens Langejürgen. 2020. Respiration parameter determination with non-obstructive methods. *Advances in Radio Science* 18 (2020), 89–95.
[37] Sophie Freeman, Martin Gibbs, and Bjorn Nansen. 2023. Personalised But Impersonal: Listeners' Experiences of Algorithmic Curation on Music Streaming Services. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3544548.3581492 event-place: Hamburg, Germany.
[38] Thomas Fuchs and Hanne De Jaegher. 2009. Enactive intersubjectivity: Participatory sense-making and mutual incorporation. *Phenomenology and the cognitive sciences* 8, 4 (2009), 465–486.
[39] Kazjon Grace, Mary Lou Maher, Douglas Fisher, and Katherine Brady. 2015. Data-intensive evaluation of design creativity using novelty, value, and surprise. *International Journal of Design Creativity and Innovation* 3, 3-4 (2015), 125–147.
[40] Matthew Guzdial, Nicholas Liao, and Mark Riedl. 2018. Co-creative level design via machine learning. *arXiv preprint arXiv:1809.09420* (2018).
[41] Matthew Guzdial, Nicholas Liao, Vishwa Shah, and Mark O Riedl. 2018. Creative invention benchmark. *arXiv preprint arXiv:1805.03720* (2018).
[42] Matthew Guzdial and Mark Riedl. 2019. An interaction framework for studying co-creative ai. *arXiv preprint arXiv:1903.09709* (2019).
[43] Ivar Hagendoorn. 2003. The Dancing Brain. *Cerebrum: The Dana Forum on Brain Science* 5 (01 2003).
[44] Carolien Hermans. 2021. Oceanic feeling: Towards a fluid philosophy of moving bodies. *Journal of Dance & Somatic Practices* 13, 1-2 (2021), 133–143.
[45] Rainbow TH Ho, Ted CT Fong, Wai Chi Chan, Joseph SK Kwan, Patrick KC Chiu, Joshua CY Yau, and Linda CW Lam. 2020. Psychophysiological effects of dance movement therapy and physical exercise on older adults with mild dementia: a randomized controlled trial. *The Journals of Gerontology: Series B* 75, 3 (2020), 560–570.
[46] Guy Hoffman and Gil Weinberg. 2010. Shimon: an interactive improvisational robotic marimba player. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. ACM, 3097–3102.
[47] Guy Hoffman and Gil Weinberg. 2010. Shimon: an interactive improvisational robotic marimba player. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. 3097–3102.
[48] Kristina Höök, Martin P Jonsson, Anna Ståhl, and Johanna Mercurio. 2016. Somaesthetic appreciation design. In *Proceedings of the 2016 chi conference on human factors in computing systems*. 3131–3142.
[49] Eva Hornecker. 2011. The role of physicality in tangible and embodied interactions. *interactions* 18, 2 (2011), 19–23.
[50] Jun Hu and Tianshi Hou. 2022. Application of Dynamic Process Neural Network Model Identification in Ethnic Dance Online Teaching System. *Computational Intelligence and Neuroscience* 2022 (2022).
[51] George Humphrey. 1923. *The story of man's mind*. Small, Maynard.
[52] Mikhail Jacob. 2019. *Improvisational artificial intelligence for embodied co-creativity*. Ph. D. Dissertation. Ph. D. Dissertation, GIT.
[53] Mikhail Jacob, Alexander Zook, and Brian Magerko. 2013. Viewpoints AI: Procedurally Representing and Reasoning about Gestures.. In *DiGRA conference*.
[54] Anna Jordanous. 2012. A standardised procedure for evaluating creative systems: Computational creativity evaluation based on what it is to be creative. *Cognitive Computation* 4 (2012), 246–279.
[55] Adrienne L Kaeppler. 1987. Spontaneous choreography: Improvisation in Polynesian dance. *Yearbook for traditional music* 19 (1987), 13–22.
[56] Jiwon Kang, Chaewon Kang, Jeewoo Yoon, Houggeun Ji, Taihu Li, Hyunmi Moon, Minsam Ko, and Jinyoung Han. 2023. Dancing on the inside: A qualitative study on online dance learning with teacher-AI cooperation. *Education and Information Technologies* (2023), 1–31.
[57] Seo Young Kim, Bernd H Schmitt, and Nadia M Thalmann. 2019. Eliza in the uncanny valley: Anthropomorphizing consumer robots increases their perceived warmth but decreases liking. *Marketing letters* 30 (2019), 1–12. Publisher: Springer.
[58] Andrea Kleinsmith and Nadia Bianchi-Berthouze. 2012. Affective body expression perception and recognition: A survey. *IEEE Transactions on Affective Computing* 4, 1 (2012), 15–33.
[59] Meha Kumar, Duri Long, and Brian Magerko. 2020. Creativity Metrics for a Lead-and-Follow Dynamic in an Improvisational Dance Agent.. In *ICCC*. 276–283.
[60] Rudolf Laban and Lisa Ullmann. 1971. *Mastery of Movement* (3rd ed.). Macdonald & Evans Ltd, London, United Kingdom.
[61] Susanne K Langer. 1953. *Feeling and form*. Vol. 3. Routledge and Kegan Paul London.

[62] Po-Ming Lee, Sin-Yu Jheng, and Tzu-Chien Hsiao. 2014. Towards automatically detecting whether student is in flow. In *Intelligent Tutoring Systems: 12th International Conference, ITS 2014, Honolulu, HI, USA, June 5-9, 2014. Proceedings 12*. Springer, 11–18.

[63] Daniel B Levinson, Eli L Stoll, Sonam D Kindy, Hillary L Merry, and Richard J Davidson. 2014. A mind you can count on: validating breath counting as a behavioral measure of mindfulness. *Frontiers in psychology* 5 (2014), 1202.

[64] Antonios Liapis, Georgios N Yannakakis, and Julian Togelius. 2013. Sentient Sketchbook: Computer-aided game level authoring.. In *FDG*. 213–220.

[65] Duri Long, Mikhail Jacob, and Brian Magerko. 2019. Designing co-creative AI for public spaces. In *Proceedings of the 2019 on Creativity and Cognition*. 271–284.

[66] Ana Lossing, Mary Moore, and Micah Zuhl. 2017. Dance as a treatment for neurological disorders. *Body, Movement and Dance in Psychotherapy* 12, 3 (2017), 170–184.

[67] Klara Lucznik. 2015. Between minds and bodies: Some insights about creativity from dance improvisation. *Technoetic Arts* 13, 3 (2015), 301–308. Publisher: Intellect.

[68] Lindsay MacDonald, John Brosz, Miguel A Nacenta, and Sheelagh Carpendale. 2015. Designing the Unexpected: Endlessly Fascinating Interaction for Interactive Installations. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. 41–48.

[69] Brian Magerko, Christopher DeLeon, and Peter Dohogne. 2011. Digital Improvisational Theatre: Party Quirks. AAAI Press, Reykjavík, Iceland.

[70] Brian Magerko and Duri Long. 2020. Why Don't Computers Improvise With Us?. In *Workshop on Artificial Intelligence for HCI at the 2020 ACM Conference on Human Factors in Computing Systems (CHI)*.

[71] Lara J Martin, Brent Harrison, and Mark O Riedl. 2016. Improvisational computational storytelling in open worlds. In *International Conference on Interactive Digital Storytelling*. Springer, 73–84.

[72] Kory W Mathewson and Piotr Mirowski. 2017. Improvised theatre alongside artificial intelligences. In *Thirteenth Artificial Intelligence and Interactive Digital Entertainment Conference*.

[73] Kory W Mathewson and Piotr Mirowski. 2018. Improbotics: Exploring the imitation game using machine intelligence in improvised theatre. *arXiv preprint arXiv:1809.01807* (2018).

[74] Marian Mazzone and Ahmed Elgammal. 2019. Art, creativity, and the potential of artificial intelligence. In *Arts*, Vol. 8. MDPI, 26.

[75] Pamela McCorduck. 1991. *Aaron's code: meta-art, artificial intelligence, and the work of Harold Cohen*. Macmillan.

[76] John McCormick, Kim Vincs, Saeid Nahavandi, Douglas Creighton, and Steph Hutchison. 2014. Teaching a digital performing agent: Artificial neural network and hidden markov model for recognising and performing dance movement. In *Proceedings of the 2014 International Workshop on Movement and Computing*. 70–75.

[77] D. J Mendonca and W. A Wallace. 2007. A cognitive model of improvisation in emergency management. *IEEE Transactions on Systems, Man and Cybernetics, Part A* 37, 4 (2007), 547–561.

[78] Masahiro Mori, Karl F MacDorman, and Norri Kageki. 2012. The uncanny valley from the field. *IEEE Robotics & automation magazine* 19, 2 (2012), 98–100.

[79] Florian'Floyd' Mueller, Richard Byrne, Josh Andres, and Rakesh Patibanda. 2018. Experiencing the body as play. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[80] Michael Muller, Justin D Weisz, and Werner Geyer. 2020. Mixed initiative generative AI interfaces: An analytic framework for generative AI applications. In *Proceedings of the Workshop The Future of Co-Creative Systems-A Workshop on Human-Computer Co-Creativity of the 11th International Conference on Computational Creativity (ICCC 2020)*.

[81] Bilge Mutlu. 2021. The Virtual and the Physical: Two Frames of Mind. *Iscience* (2021).

[82] Daniel Nagrin. 1994. *Dance and the specific image: Improvisation*. University of Pittsburgh Pre.

[83] MA Notturno and Karl Popper. 2013. *Knowledge and the Body-Mind Problem: In Defence of Interaction*. Routledge.

[84] Lior Noy, Erez Dekel, and Uri Alon. 2011. The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences* 108, 52 (2011), 20947–20952.

[85] Brian O'Neill, Andreya Piplica, Daniel Fuller, and Brian Magerko. 2011. A knowledge-based framework for the collaborative improvisation of scene introductions. In *Interactive Storytelling: Fourth International Conference on Interactive Digital Storytelling, ICIDS 2011, Vancouver, Canada, November 28–1 December, 2011. Proceedings 4*. Springer, 85–96.

[86] Brian O'Neill, Andreya Piplica, Daniel Fuller, and Brian Magerko. 2011. A Knowledge-Based Framework for the Collaborative Improvisation of Scene Introductions.. In *ICIDS*. Springer, 85–96.

[87] Amandine Pras, Michael F Schober, and Neta Spiro. 2017. What about their performance do free jazz improvisers agree upon? A case study. *Frontiers in psychology* 8 (2017), 966.

[88] Jeff Pressing. 1988. Improvisation: methods and models. In *Generative processes in music*, John Sloboda (Ed.). Oxford University Press, Canada, 129–178.

[89] Sally A Radell, Daniel D Adame, and Stephen P Cole. 2003. Effect of teaching with mirrors on ballet dance performance. *Perceptual and motor skills* 97, 3 (2003), 960–964.

[90] Katerina El Raheb, Marina Stergiou, Akrivi Katifori, and Yannis Ioannidis. 2019. Dance interactive learning systems: A study on interaction workflow and teaching approaches. *ACM Computing Surveys (CSUR)* 52, 3 (2019), 1–37.

[91] Katerina El Raheb, George Tsampounaris, Akrivi Katifori, and Yannis Ioannidis. 2018. Choreomorphy: A whole-body interaction experience for dance improvisation and visual experimentation. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces*. 1–9.

[92] Katerina El Raheb, George Tsampounaris, Akrivi Katifori, and Yannis Ioannidis. 2018. Choreomorphy: A Whole-Body Interaction Experience for Dance Improvisation and Visual Experimentation. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces* (Castiglione della Pescaia, Grosseto, Italy) *(AVI '18)*. Association for Computing Machinery, New York, NY, USA, Article 27, 9 pages.

[93] Susanne Ravn. 2020. Investigating dance improvisation: from spontaneity to agency. *Dance Research Journal* 52, 2 (2020), 75–87.

[94] Susanne Ravn. 2022. Embodied Learning in Physical Activity: Developing Skills and Attunement to Interaction. *Frontiers in Sports and Active Living* (2022). https://doi.org/10.3389/fspor.2022.795733

[95] Jeba Rezwana and Mary Lou Maher. 2022. Designing Creative AI Partners with COFI: A Framework for Modeling Interaction in Human-AI Co-Creative Systems. *ACM Transactions on Computer-Human Interaction* (2022). Publisher: ACM New York, NY.

[96] Monica M Ribeiro and Agar Fonseca. 2011. The empathy and the structuring sharing modes of movement sequences in the improvisation of contemporary dance. *Research in Dance Education* 12, 2 (2011), 71–85.

[97] Mark O Riedl. 2019. Human-centered artificial intelligence and machine learning. *Human Behavior and Emerging Technologies* 1, 1 (2019), 33–36.

[98] Wolff-Michael Roth. 2001. Gestures: Their role in teaching and learning. *Review of educational research* 71, 3 (2001), 365–392.

[99] Katia Savrami. 2017. A duet between science and art: Neural correlates of dance improvisation. *Research in Dance Education* 18, 3 (2017), 273–290.

[100] R Keith Sawyer. 2014. *Group creativity: Music, theater, collaboration*. Psychology Press.

[101] R Keith Sawyer and Stacy DeZutter. 2009. Distributed creativity: How collective creations emerge from collaboration. *Psychology of aesthetics, creativity, and the arts* 3, 2 (2009), 81.

[102] Martijn J Schuemie, Peter Van Der Straaten, Merel Krijn, and Charles APG Van Der Mast. 2001. Research on presence in virtual reality: A survey. *Cyberpsychology & behavior* 4, 2 (2001), 183–201.

[103] Frederick A Seddon. 2005. Modes of communication during jazz improvisation. *British Journal of Music Education* 22, 1 (2005), 47–61.

[104] Sakib Shahriar. 2022. GAN computers generate arts? a survey on visual arts, music, and literary text generation using generative adversarial network. *Displays* 73 (2022), 102237. Publisher: Elsevier.

[105] Job Simulator. 2016. the 2050 Archives.

[106] Rebecca A Smith and Emily S Cross. 2023. The McNorm library: creating and validating a new library of emotionally expressive whole body dance movements. *Psychological Research* 87, 2 (2023), 484–508.

[107] Katta Spiel. 2021. The bodies of tei–investigating norms and assumptions in the design of embodied interaction. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. 1–19.

[108] Catherine Stevens, Stephen Malloch, Shirley McKechnie, and Nicole Steven. 2003. Choreographic cognition: The time-course and phenomenology of creating a dance. *Pragmatics & Cognition* 11, 2 (2003), 297–326.

[109] S Studios. 2016. Everest VR.

[110] Carlota Torrents, Natàlia Balagué, Ángel Ric, and Robert Hristovski. 2021. The motor creativity paradox: Constraining to release degrees of freedom. *Psychology of Aesthetics, Creativity, and the Arts* 15, 2 (2021), 340.

[111] Carlota Torrents Martín, Ángel Ric, and Robert Hristovski. 2015. Creativity and emergence of specific dance movements using instructional constraints. *Psychology of Aesthetics, Creativity, and the Arts* 9, 1 (2015), 65.

[112] Milka Trajkova. 2020. Designing AI-based feedback for ballet learning. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–9.

[113] Milka Trajkova and Francesco Cafaro. 2018. Takes Tutu to ballet: Designing visual and verbal feedback for augmented mirrors. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 1 (2018), 1–30.

[114] Milka Trajkova, Francesco Cafaro, and Lynn Dombrowski. 2019. Designing for ballet classes: Identifying and mitigating communication challenges between dancers and teachers. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. 265–277.

[115] Milka Trajkova, Manoj Deshpande, Andrea Knowlton, Cassandra Monden, Duri Long, and Brian Magerko. 2023. AI Meets Holographic Pepper's Ghost: A Co-Creative Public Dance Experience. In *Companion Publication of the 2023 ACM Designing Interactive Systems Conference*. 274–278.

[116] Laia Turmo Vidal, Elena Márquez Segura, and Annika Waern. 2023. Intercorporeal Biofeedback for Movement Learning. *ACM Trans. Comput.-Hum. Interact.* 30, 3, Article 43 (jun 2023), 40 pages.

[117] Takane Ueno, Yuto Sawa, Yeongdae Kim, Jacqueline Urakami, Hiroki Oura, and Katie Seaborn. 2022. Trust in human-AI interaction: Scoping out models, measures, and methods. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. 1–7.

[118] Floor van Alphen. 2014. Tango and enactivism: first steps in exploring the dynamics and experience of interaction. *Integrative Psychological and Behavioral Science* 48, 3 (2014), 322–331.

[119] Freya Vass-Rhee. 2010. Auditory turn: William Forsythe's vocal choreography. *Dance Chronicle* 33, 3 (2010), 388–413.

[120] Dusya Vera and Mary Crossan. 2005. Improvisation and innovative performance in teams. *Organization science* 16, 3 (2005), 203–224.

[121] Yingping Wang and Guang Zheng. 2020. Application of artificial intelligence in college dance teaching and its performance analysis. *International Journal of Emerging Technologies in Learning (iJET)* 15, 16 (2020), 178–190.

[122] Lauren Winston and Brian Magerko. 2017. Turn-Taking with Improvisational Co-Creative Agents. In *Proceedings of the Thirteenth Artificial Intelligence and Interactive Digital Entertainment Conference (AIIDE '17)*. AAAI, Snowbird, UT.

[123] Shu-Fen Wu, Yu-Ling Lu, and Chi-Jui Lien. 2021. Detecting students' flow states and their construct through electroencephalogram: Reflective flow experiences, balance of challenge and skill, and sense of control. *Journal of Educational Computing Research* 58, 8 (2021), 1515–1540.

[124] Yingyi Xu. 2022. Deep learning for dance teaching system. In *Innovative Computing: Proceedings of the 4th International Conference on Innovative Computing (IC 2021)*. Springer, 1577–1581.

[125] Liangliang Zhang. 2022. Improved Graph Convolutional Neural Network for Dance Tracking and Pose Estimation. *Computational Intelligence and Neuroscience* 2022 (2022).

[126] Yun Zhong, Fan Zhang, and Yiannis Demiris. 2023. Contrastive Self-Supervised Learning for Automated Multi-Modal Dance Performance Assessment. In *ICASSP 2023-2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 1–5.

[127] Qiushi Zhou, Louise Grebel, Andrew Irlitti, Julie Ann Minaai, Jorge Goncalves, and Eduardo Velloso. 2023. Here and Now: Creating Improvisational Dance Movements with a Mixed Reality Mirror. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–16.

[128] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 493–502.