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FORTHCOMING IN THE SPECIAL ISSUE: TECHNOSCIENTIFIC PRACTICES OF MUSIC; CRITICAL IMPLICATIONS OF NEW TECHNOLOGIES

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Musical intra-actions with digital musical instruments

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ABSTRACT

This article explores the evolving dynamics between musicians and technological artifacts. Building on Karen Barad's concept of intra-action, I intend to show how musicians and digital musical instruments (DMIs) mutually shape, influence, and transform one another. This perspective shifts the view of technologies from purely functional tools to an integral part of a larger system. I aim to explore the concept of musical intra-action with DMIs, suggesting that the capacities of all entities, both human and non-human, to affect music production emerge through their mutually constitutive relationships. To support this investigation, I analyse the results of a workshop I organised with musician-scholars, alongside subjective observations from studio sessions. By focusing on the mutual entanglements, I aim to show how musical intra-action might enable a more relationally incorporated music production process, in which musicians and technological entities are co-constituted, dynamically shaping and transforming one another and their contributions.

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Musical intra-action; mutual incorporation; intra-action; digital musical instruments; artificial intelligence; collaborative creativity; material conditions

Introduction

Collaborative efforts in a music production might not always run as smoothly as one might imagine, as they can often carry the weight of past challenges and difficulties. The experience of semi-professional jazz musician Howard S. Becker, more of a scholar contributed significantly to sociology of art and music, highlights some of the difficulties of working together collaboratively in a music production, suggesting that, to be successful, musicians need to 'pay close attention to the other players', 'develop a collective' and allow the music to emerge from the performance (Becker, 2000, p. 172). These issues of collaborative creativity become even more complex, particularly when considering the role of technology in music production with digital musical instruments (DMIs). By positioning technologies as an inextricable part of how musicians think about and engage in music-making, practices involving advanced technologies, such as autonomous or generative artificial intelligence (AI) models, challenge our understanding of collaborative creativity and broaden current thinking in the NIME field[1] within the context of entanglement theory (Frauenberger, 2019; Morrison & McPherson, 2024; Reed et al., 2024), agency (Mudd, 2019; Sergeant, 2016; Tahiroğlu, 2021), sociality (Waters, 2021), and the creative influence of tools in music production (Bowers et al., 2016; Detweiler et al., 2022; Melbye, 2022).

All musical instruments are technologies, and all instruments condition how musicians think and act on music. Traditional acoustic instruments like the piano or violin are the result of centuries of technological evolution. Each instrument introduces physical, mechanical, sonic and expressive constraints on the musician, which in turn shapes the musician's artistic expression. This brings us to the fundamental question: Is the difference then between traditional instruments and instruments with more advanced technologies, such as AI systems, just a matter of degree (quantitative), or is it something significantly new (qualitative)? Thor Magnusson's (2009) argument in 'Of Epistemic Tools: Musical Instruments as Cognitive Extensions' leans toward qualitative distinctions that DMIs offer in terms of interaction and feedback, embodied experience, epistemic implications, affordances and constraints, and cultural context. Magnusson (2009) argues that DMIs represent a new paradigm in music production. They are cognitive extensions that shape the way musicians think, understand, create and engage in music, yet are no longer simple extensions of the musician's body and mind.

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[1] New Interfaces for Musical Expression (NIME) is an established and interdisciplinary research field that has been exploring the development and use of advanced music technologies for musical expression since 2001. It focuses on designing, evaluating, and applying new musical instruments and interfaces, often integrating knowledge and practices from fields such as human-computer interaction, computer music, and interface design.

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For example, AI systems are indeed part of a broader trend in the technological advancement of musical instruments today. They continue the historical relationship between musicians and the tools they use to create music, but in a qualitatively different way. This qualitative difference is specifically distinct from the notion of embodied musical instruments, those that integrate the physical actions, sensory feedback, and cognitive processes of musicians as central to their design, sound production and performance. Embodied musical instruments advance performance by allowing intuitive control through familiar physical gestures or movements with a cognitively tighter connection between intent and execution (Leman, 2007). This relationship is critical for performing complex techniques, conveying the intended expressive interpretations, and playing the instrument with accuracy and fluency, through which the musician becomes the primary agent in music practice. The idea of the musician as the primary agent is challenged by the appearance of AI systems in the music productions, not only because they introduce a new layer of epistemic complexity into music practice but also because the autonomous features of AI systems can influence the musical output in various unpredictable ways as the behaviour of AI systems can change dynamically in response to the musician's input. These technologies increasingly fulfil roles that combine active participation in creative effort and technical execution, consequently redefining creative contribution and the collaborative relationship between musician and their technological tools.

In view of the evolving relationship between musicians and their technological tools, it becomes necessary to shift our perspective on collaborative creativity from one of primary agent actions to one of dynamic, *mutual entanglement*. Karen Barad, a physicist and a feminist theorist, provides an interesting framework for understanding this shift. Barad's (2007) notion of intra-action introduces the concept of entangled agencies, mutually constituting each other within a dynamic relational system, where both human and non-human entities continuously influence and shape one another. Unlike the conventional concept of interaction, which takes for granted pre-existing boundaries or individual attributes independently of their interactions, the idea of intra-action suggests that entities gain their properties and identities through their intra-actions (Barad, 2007). According to Barad, these entities are only considered separate in a relational sense. This means they become present in relation to their interconnectedness, lacking individual existence in isolation. Rather than viewing musicians and instruments – be they traditional or AI systems – as separate entities that simply interact, intra-actional framework emphasises their constant 'reconfiguring of the world' (Barad, 2007, p. 170). In such a musical ensemble, each group member's creative contributions and interpretive acts are inherently tied to and shaped by the ensemble's intra-actions. Intra-action redefines the understanding of agencies, actions, and phenomena, meaning that the phenomenon of an action is deeply embedded in the co-constitutive relationship of those agencies. Therefore, the very nature of each entity (both human and non-human) and their capacities to affect music production is co-determined through these complex webs of relationships. By incorporating the intra-active view, we move beyond the commonly known notion of musical instruments being extensions of human intention, recognising that all participants are not static attributes but dynamic enactments in a constantly reconfigured creative process.

Building on Barad's framework, in this article, I bring into focus the mutual incorporation that comes into play to achieve musical experience through mutual entanglement (i.e. a musician and musical instrument as a relationship of relationships) and explain that this incorporation itself is not about the differentiation of the entities involved in the social, but instead, about the interdependence of the incorporated in music production. I aim to explore the concept of *musical intra-action* with DMIs, where the relationships of all incorporated of the social and their interdependencies with each other are organised and reconfigured mutually in a socially engaged practice.

Later in the article, I present and discuss the outcomes of the workshop I conducted with musician researchers, as well as the studio sessions recorded with an AI musical instrument, as means to present my viewpoints on what I believe is potentially inherent in the mutual incorporation of musicians and technologies. This perspective is essential for understanding how technologies become entangled with musicians and, consequently, how we engage with music and music-making.

Mutual incorporation of musicians and technologies in music production

Becker introduces the collaborative creativity in ways the jazz musicians follow and practice certain conventions or 'etiquette' that 'calls attention to the granting of equal status to everyone's ideas', which enables collective improvisation (Becker, 2000, p. 173). This etiquette includes respecting the contributions of others, maintaining a coherent collective direction, and being responsive to subtle cues from other musicians. The mutual behaviour ensures that the music remains cohesive, exciting and engaging for both performers and audiences.

Becker emphasises further that while the etiquette can appear to constrain individual freedom, it facilitates creativity by providing a structured environment where new ideas can emerge through collaborative effort. Questioning how improvisation is not the absence of structure but rather involves varying degrees of predetermined elements and spontaneous creation, Keith Sawyer (2000, p. 180) calls such music performance 'a collective social process', where the creativity of an improvisational act arises from the interactions of the group members. For Sawyer (2000), in a successful group improvisation, no single performer can be credited with the creativity of the outcome; rather, it is the result of the relationship and mutual responsiveness of the entire group. It would not be too much to recognise this social practice as a process where each musician's input is integrated into the collective performance in all possible ways musicians engage in mutually.

The collaborative creativity seen in jazz ensembles provides a perspective through which we can explore NIME ensembles[2], where the mutual entanglements between musicians and technologies push collective creativity and technological advancements. This perspective may be framed and guided by Bernard Stiegler's (1998, 2010a, 2010b) philosophical approach to the co-evolution of humans and technology. To begin with, Stiegler's (1998) understanding of human technology relationship, as it is grounded in the idea that technology and humanity co-evolve, with each influencing the development of the other, provides useful insights into the entanglements of musicians and technologies in music production. Stiegler rejects the traditional notion of 'human nature' as the conscious, rational, non-technical agent; instead, for Stiegler technics and technology are temporally prior to the human nature which is 'profoundly transformed' that exceed 'human inventing the technical' (Stiegler, 1998, p. 20 &, p. 137). What defines human is the technics capacities and the potential for unlimited transformation; beings who evolve not only biologically but also through their technical systems. These transformations aren't just limited to physical manifestations but extend to cognitive capacities, such as human memory and knowledge, which are deeply connected with technological evolution (Stiegler, 1998). Technics, in Stiegler's conceptualisation, are prior to human nature, and their fundamental nature lies as much in shaping human experiences and capabilities as in being shaped by them. Stiegler (1998) also emphasises that technics play a crucial role in processes of individuation (how individuals understand and construct their identities) and the formation of collective social structures (how they relate to others in society). Stiegler's argument extends beyond physical tools to include technics like computation and digital technologies, framing them as central to human memory, culture, and temporality.

The idea of co-evolution of technologies and humans, along with Stiegler's stages of technological integration, translates itself to the field of music production and demonstrates how tools shape and co-construct creative processes. In line with the co-evolution idea, technologies eventually develop their own trajectories, sometimes leading to new societal norms and unintended consequences within the cultural practice of music. This dual nature of technology, which Stiegler (2010b) refers to as pharmacological, can be both beneficial and harmful. The concept of pharmacology presents an interesting viewpoint, where technology is seen as both a 'remedy (the support) and poison (the ruin)' – capable of enhancing and disrupting human life (Stiegler, 2010b, p. 163). In music production as well, they can enter and pharmacologically change us. Bijsterveld and Peters (2010) discuss the unintended consequences of music-making tools, particularly how the sociotechnical aspects of musical instruments introduce new creative possibilities while simultaneously constraining traditional forms of musical expression. This approach resonates with Stiegler's concept of poison and remedy: musical instruments can enable new forms of creativity while also introducing disruptions to traditional practices.

For the present purpose of the article, I further underline what Stiegler (1998) points out strongly in his seminal book 'Technics and Time, 1: The Fault of Epimetheus': technologies are integral to human existence, shaping how humans perceive themselves, relate to others, and transform their collective and societal organisation. Given this, we should consider technological entities not external to human existence but fundamentally entangled with our very being, influencing and co-evolving with human nature. Stiegler's perspective suggests that technologies reconfigure the musician's relationship with music production by externalising memory and skill, thus transforming the cultural repository from which creative individuals source their inspiration and methods.

Technologies embody a material memory of cultural evolution, preserving the history, knowledge, practices, and transformations of a culture over time (Latour, 2005). Music technologies, similarly, carry this material memory, facilitating new possibilities for creation, distribution, and consumption while engaging with societal dynamics to reshape collective structures, such as social identities tied to music production. These technologies not only introduce novel workflows and genres but also redefine cultural norms around music accessibility and production practices. In this way, they are both a reflection of cultural evolution and instrumental in its continued transformation.

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[2] These ensembles in a NIME context often include non-traditional, custom-designed and technologically advanced musical instruments that expand the possibilities of musical performance.

Stiegler's ideas as well suggest us to reframe this dynamic, emphasising the co-evolutionary relationship between musicians and their technological tools. By situating music technologies as integral to human practices rather than mere tools, Stiegler's framework highlights the processes of incorporation and entanglement – how musicians internalise technological possibilities and how tools, in turn, shape creative agency.

Transformative shifts in musicians' practices

There have been considerable efforts to provide a broader understanding of the co-evolution of emerging music technologies and their impact on developing collaborative models in music production. For example, studies on creative partnerships between humans and computers have demonstrated that even simple meta-creative systems can stimulate engaging and challenging interactions, suggesting that such partnerships can enhance creative outcomes in ways that go beyond the capabilities of individuals working alone (Brown et al., 2017). Additionally, a framework for sound and music computing has been introduced, which allows humans to guide artificial agents in navigating musical environments through interactive reinforcement learning (Scurto et al., 2018). This framework shows how technology and human creativity can merge to explore new musical possibilities, further supporting the idea that of the mutual human and machine corporation can lead to exceptional advancements in music production. Recognising the importance of emerging music technologies and their impact, as well as the need to better understand collective creativity through music practitioners' co-creation processes involving musicians and technological entities, I organised a workshop on November 10, 2022, at Oodi Library in Helsinki. The workshop involved seven invited musician-scholars, who are making significant contributions to new music research today. The workshop offered deeper insights into how the practices of musician-researchers extend beyond physical and acoustic phenomena, how technology influences their artistic expression, how they interact with both human and non-human actors, and how their musical activities are inherently embedded in social contexts. This workshop enabled further analysis of co-creative collaborations among humans, non-humans, and artificial intelligence in music production.

Musicians, AI agents and co-creation

The musician-researchers who participated in the workshop have research interests that range from the study of music performance to human–computer interaction, and from sound and music computing to cultural philosophy. They focus strongly on exploring new technologies for creative expression. Their combined experience in research, performance, and teaching offers deep insights into the complex relationship between musicians and technology, providing a detailed understanding of their entanglements.

The participants engaged in a series of open-ended questions, taking turns for their questions as well as collaboratively developing the discussion. The workshop was structured under three main subtopics: workflow, creative use of AI tools and co-creation. In the 'co-creation' section of the workshop, participants shared their thoughts on the most challenging aspects of their collaboration processes. We particularly discussed how these collaborations facilitate mutual influence and build collective intelligence, leading to new aesthetics, meanings, and experiences that could not be achieved by any one entity alone. The following questions guided our discussion: How would you describe the role of technologies (e.g. AI systems) or human actors as collaborators? In what ways does mutual influence and collective intelligence manifest in your collaborations, and how do these dynamics lead to new artistic outcomes? Through this dialogue, in this workshop we aimed to understand the transformative potential of collaborative creativity in music practices with emerging technologies.

Analysis

I followed thematic analysis, a method introduced in the field of psychology that focuses on identifying patterns and themes within qualitative data (Braun & Clarke, 2006). This approach enabled the development of a thematic framework, informed by the qualitative responses to the questions and the discussions. After transcribing the audio recordings, I familiarised myself with the data and identified recurring themes in the transcript. The analysis focused on three main questions: the challenging and interesting aspects of the collaboration process, the role of AI, technologies and human actors as collaborators, and the manifestation of mutual influence in collaborations. The issues that emerged from the participants included limitations in maintaining and facilitating performance, the notion of the black box in AI, the shared process of understanding in collaborations, the iterative nature of reacting and performing, unexpected behaviours in AI, and more. Looking at how these issues mapped on to the practice of music making and by combining them in groups allowed to identify high-level themes: 'Disruption and Flow in Collaboration', 'Participatory Sense-Making' and 'Material Conditions and Agency'.

After clarifying the scope of these emerging themes, I revisited the transcript to extract a potential narrative not originally intended by the workshop questions. Key elements – such as creative exploration, shared artistic understanding, uncertainty, and unrealised potential – emerged as interconnected themes related to music production. These themes then served as points of discussion in the context of a high-level thematic analysis.

Disruption and flow in collaboration

Disruption and Flow in Collaboration reflects the range of responses participants gave to questions of the challenges in collaboration in music production. Participants discussed the balance between maintaining flow in improvisational performances and the need for occasional disruption. It was noted that performances that are 'too flowy' might lose engagement with the audience. This is something we can link to one of the idealisms musicians are bringing too often in collaborative music production, which is all about agreement, overemphasising flow too much. Musicians might feel great to play, where they fold in on themselves and they might be paying great attention to what they're doing, but they're not necessarily keeping that bond going with the audience because they are focusing too much into what is going on between them.

> So that you don't necessarily need to find consensus … sometimes we're actually deliberately causing disruption, reducing resistance, is quite often what I'm trying to do, particularly if you're trying to make an artificial co-player, one of the traps that's really easy to fall into is that you start trying to make a whole model of music, all music!! (participant #1)

One of the participants mentioned using a device, named *regulatory capture*, that disrupts transitions by bringing back remixed utterances, forcing the group of performers to adapt and stay engaged. Regulatory capture is using an AI algorithm which is in one way misused to do unsupervised feature learning. It is essentially trying to build a model of the performing musicians' interactions from scratch each time one presses the reset button. Primarily, it prevents musicians from becoming complacent, encouraging them to pay attention to each other, to understand the impact of the regulatory capture and to find ways to work around it. This interconnectedness of stability and disruption, matter and meaning, and the way material configurations shape and are shaped by human actions, aligns with Barad's notion of intra-action (Barad, 2007).

> What is the role of the collaborator for me? Not only a partner, but an instigator in terms of we have a mutual responsibility towards each other. What do we play? How we go on about this? Basically, saying we're in it together. (participant #5)

The process of navigating creative disruptions captures how musicians manage and utilise interruptions, both from technology and human interactions, to enhance their creative flow. Rather than aiming for seamless collaboration, the participants in the workshop described the benefits of 'deliberate disruptions'.

Participatory sense-making

Participatory Sense-Making is central to the processes of practicing, preparing, composing and performing in music production. This concept extends beyond any specific musical style and the technologies that may or may not be used in musical production. Although Participatory Sense-Making was not a specific question in the workshop, it emerged as an important theme in the responses. It emphasises the importance of mutual influence and the iterative nature of reacting to each other's inputs, at the same time, it expands the original concept of Participatory Sense-Making introduced by Fuchs and De Jaegher (2009) and aligns closely with Barad's notion of intra-action.[3] Participatory Sense-Making theme describes how musicians and AI systems co-create meaning through shared processes of making sense of their interactions, where the collaborative process itself becomes a way to understand and explore new artistic possibilities.

> … . what this brings to the aesthetics and the meaning part of it is about the shared process of making sense. So, if art making and art doing in general is about making sense of the world and doing it together, then it is about participatory sense making. And one of the things that we make sense of when we're using this stuff (code, material, instrument, technologies[4]) is the stuff itself. (participant #1)

Interestingly, the discussion on the shared process of making sense revealed two slightly distinct perspectives on the nature of black box in AI technologies. One viewpoint emphasised the challenges appeared by the increasing complexity of AI systems, mentioning that musicians find it difficult to understand the reasons behind these technologies' failures or glitches. The lack of interpretability or explainability becomes especially problematic, as it limits their ability to respond to those patterns of failure behaviour in creative and productive ways. Another viewpoint argued that the nature of black boxes in AI might not be as problematic as often discussed. This perspective drew an analogy to acoustic instruments, where musicians may not fully understand the technical details of the instrument's construction but can still master its use through experience and practice.

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[3] Fuchs and De Jaegher (2009) introduced the concept of Participatory Sense-Making that refers to the co-creation of meaning through social interaction and mutual engagement. While in their framework, sense-making is not seen as an isolated activity limited to an individual's cognitive process but rather as an inherently interactive phenomenon, it still focuses more narrowly on the social and interactive aspects of human cognition and sense-making processes. Barad's notion of intra-action extends this idea to a broader level, involving both human and non-human agents and challenging traditional notions of independent entities (Barad, 2007).

[4] The text in the parenthesis belongs to me, this is to spot the context that the participants were refering to in the workshop.

> And if you think about analogues in acoustic music, for instance, plenty of amazing violinists are not luthiers. They're not physicists! In many ways, the violin apparatus is also a black box, but they have all of this experience with it that allows them to do the things that they need to do. There are certain things you do need to learn, but a lot of that learning can be experiential. It can be practice driven. When people think about opening up the black box, it's often about exposing a rationale for why things happen in a particular way. (participant #4)

The converse view suggests that while some rational or mathematical understanding of the AI system can be beneficial, it is not always necessary for effective use. The key lies in practical application and the ability to adaptively reconfigure responses to the AI system's behaviour in achieving creative goals. These responses resonate with the Participatory Sense-Making theme by emphasising that the collaborative process is enriched through experience and practice, rather than only through technical comprehension.

At the same time, the Participatory Sense-Making theme is linked with explicating what musicians' and performers' personal values are. It is important to note that while these values are deeply personal, they are often shaped by various external influences. Individuals are shaped by their communities of practice, including the disciplinary communities they belong to or identify with, as well as broader societal norms. These social norms could also set the social goals in music production, making collaborative music production a process of navigating, understanding, establishing, and achieving the social goals. For example, in some human and machine collaborations with AI systems, it was pointed out in the workshop that it can happen through establishing the training data set, reinforcing particular shared ideas, and adding them to the training data set.

Participants were further asked to indicate what values appeared to be significant in human-machine collaborations. A reasonably good correspondence was highlighted: technologies inherently carry the values of their creators and the communities they originate from. Some scholars have examined how these values are embedded within technological systems (McPherson & Tahıroğlu, 2020). However, identifying and analysing these inscribed values can be challenging. This difficulty arises because many machines, technologies, and systems present themselves as transparent or universal, masking the underlying values they embody (Akrich, 1992; McPherson & Lepri, 2020).

> We're not 'mining the silicon', so there's someone else's values are inscribed in the tools we're using. And so, once we sort of start to understand and adopt a critical position toward what those are, then we can start to have really interesting and compelling kind of collaborations. (participant #1)

Material conditions and agency

In our inquiry into the conditions of technology, we have discussed how materials, whether digital, analogue, or everyday artifacts, have their own agency and influence in the creative process. One participant mentioned that AI is often seen as the primary agent in contemporary art making, overtaking the agency inherent in other technologies and materials. Other participants also argued on that view, pointing out that there's no distinction between AI systems and other digital or analogue technologies, as all contribute distinctively to the art-making process. This perspective encourages a broader view of material and agency that includes various tools and objects used by artists.

> We're saturated in this conversation where people are imagining that AI is the thing that's bringing agency into art making. I don't see a hard line between AI and other digital technologies, other analogue technologies, artifacts in the everyday world. They all bring that; I think AI manifests slightly. (participant #4)

Another participant pointed out that not only physical objects but also other materials like sound have agency. Through the concept of 'sound-ware', it is suggested that sound itself prompts specific responses from the artist, much like how physical materials do. This viewpoint expands the discussion of agency beyond tangible objects to include the intangible aspects of art making, such as sound, which can influence the direction and nature of the artistic process.

> In terms of affordance, we talk mainly about material things, but the sound you have the piece asks for it. So that's really affordance of the sound. It's not the hardware, but it's what I call the 'sound-ware'. It's the soundware you respond to. It's not only the material thing. And we are, I think mostly maybe used to thinking in those terms. (participant #6)

The discussion further explored the relational aspect of agency in music productions. One participant referenced Karen Barad's notion of 'co-constitution,' where the identity and role of the artist are as much shaped by the materials they interact with as the materials are shaped by the artist (Barad, 2007). This interconnectedness blurs the boundaries between the artist and the materials, suggesting a symbiotic relationship where both are integral to the creation and experience of the artwork.

The Material Conditions and Agency theme highlights the complexity of agency in art making, suggesting that materials – whether physical or other material – play an active role in shaping artistic outcomes. By recognising the diverse sources of agency, musicians can better understand the nature of their creative collaboration processes and the complex interactions that contribute to their work. In the following section, I introduce the concept of musical intra-action, which emerged from analysing high-level themes and demonstrate how the 'intra-actional' perspective has the potential to offer new perspectives to collaborative creativity in music productions.

> For Barad, it wouldn't be you and the (music[5]) piece, it would be you-piece. (participant #1)

Synthesis of the high-level themes

The high-level themes emerging from the workshop can be considered as a sort of broad overview. At first, when considering any form of collaboration in music production, participants agree that having continuous consensus and overemphasising flow can be frustrating. It is also important to note that some musicians nonetheless engage with collaborative music making despite these frustrations, just because of '*mutual responsibility towards each other*' (participant #5). At other times, as the collaboration develops, a kind of understanding between the collaborators leads to a smoother workflow when musicians overcome certain potential conflicts and give space to each other, something what Becker (2000) suggested for a successful collaborative creativity. The high-level theme, Disruption and Flow in Collaboration, is something very mutual, as '*we're in it together*' (participant #5) and is deeply rooted in shared intentions and adaptive activities.

The following high-level theme, Participatory Sense-Making, places itself in the spectrum where it firmly touches to the other high-level themes. It confirms something we know about music. Music-making emerges as a social construct, '*making sense of the world and doing it together*' (participant #1), where meaning is co-constructed. We are used to reflect the interrelations of composers, performers, audience and listeners. However, music production has hardly dealt with the social construct of the technological tools that musicians are using (Tahiroğlu & Magnusson, 2021). Recognising such participatory sense-making in music production is essential for understanding how these entities intra-act, or mutually influence and define each other within the production process. The Participatory Sense-Making high-level theme adds the *incorporation* to the concept of *mutual* highlighted by the previous high-level theme.

The third high-level theme, Material Conditions and Agency, is a key to understand the mutual influence in music production, manifesting the idea of reciprocity in which the relationships between musicians and technologies become present and make mutual dependence and interdependence relationships in music production more explicit. As musicians collaborate with instrument materials, they engage in a complex relationship, where the materials affect and inform the music (Tahiroğlu et al., 2020b). The concept of materials and human activities co-creating each other has been discussed as a framework for understanding the material agency in scientific, technological and everyday practices (Ingold, 2010; Pickering, 2010), as material and social entanglements in music practices (Born, 2013) as well as an interdependent listening experience, which is shaped by the materials that mediate between the source, cause, and effect (Kane, 2014).

By synthesising insights from these high-level themes, the concept of musical intra-action emerged, offering an integrated understanding. This understanding does not manifest as a state of balanced or unstable union of two or more living and non-living organisms, nor as a harmonious process, but rather as an entanglement of reconfigurations integral to music production. The shift towards intra-actional relationships between musicians and technologies is important in understanding the ways musicians relate to music changes and provides practical insights into collaborative-creativity workflows and material conditions in music productions.

Musical intra-action

I would like to return to Barad's (2007) conceptual framework, which suggests that material conditions are not just pre-existing facts about the world that exist independently of cultural or human processes. Instead, they are phenomena that are themselves constantly being produced and changed through our material-discursive practices and actions. Barad's concept of agential realism suggests that 'matter and meaning are not separate'; rather, they co-emerge (Barad, 2007, p. 3). In other words, Barad sees material conditions as being entangled with notions of agency and discourse. As such, they are not static or fixed but part of an ongoing process of construction and change.

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[5] The text in the parentheses belongs to me.

Barad's notion of material conditions challenges traditional distinctions between subject and object, culture and nature or musician and musical instrument. By considering instrument materials as agencies, musicians recognise the importance of material adaptability, responsiveness, and reciprocity in music-making. This recognition advances an inclusive, interconnected, and creative collaborative approach to music production.

Musicians co-evolve in Stiegler's (1998) terms with their instrument materials, collaboratively influence each other, extending their own reach and capabilities. Understanding music production as a socially engaged practice requires acknowledging these complex relationships and the mutual incorporation of all entities involved. In the very nature of collaborative creativity, music's ephemerality – its transient and temporal nature – encourages musicians to challenge its material implications, recognising that every sound and rhythm contributes to a continuous process of re-materialisation. Each rehearsal, performance and studio session become an act of re-creation, where musicians and instrument materials intra-act to reshape both the musical outcome and each other. The ongoing cycle of creation and re-creation emphasises the importance of adaptability and re-configuration, as musicians must continuously negotiate and integrate their individual contributions into the evolving collective sound. Building upon Barad's concept of intra-action rather than interaction, the notion of collective creativity shifts towards the concept of musical intra-action.

The concept of musical intra-action also builds on similar lines of thought in the NIME field that accounts for the entangled relationships between musicians and technologies and encourages a rethinking of more interconnected music-making practices with DMIs. In the context of agency of technological entities and the entanglement between human and non-human entities in music production, studies such as those by Frauenberger (2019), Morrison and McPherson (2024), and Reed et al. (2024) discuss how technology and musicians become entangled in ways that challenge traditional notions of authorship, creativity, and interaction, where technology and human agency are inseparable. Similarly, Mudd (2019) and Sergeant (2016) discuss the theory of agential realism, in ways entities, both human and technological, gain agency through their interactions, recognising the co-agential role of instruments. The impact of tools on creativity is another critical area of exploration of entangled relationships in NIME, as Bowers et al. (2016), and Melbye (2022) have demonstrated that the instruments and technologies used in music production are not passive; they profoundly influence the creative process, opening some possibilities while constraining others.

However, the concept of musical intra-action has the potential to challenge the current theoretical framework for NIME by suggesting that music production is a continuously reconfigured creative process. While this concept aligns well with the 'entanglement design' approach (Morrison & McPherson, 2024, p. 13) and 'material-oriented' perspective (Mudd, 2019, p. 124), at the same time it adds a layer of temporal dimension, *co-evolution*. In musical intra-action approach, both musician and technological entities continuously influence each other's capabilities and reshape what they can accomplish together through intra-action. In line with Barad's (2007) notion of intra-action, musical intra-actions are not static; they occur within evolving temporal contexts that shape the trajectories of both musicians and technological entities. This evolving intra-action may reconfigure the creative potential of tools and musicians while simultaneously reshaping the social and cultural meanings associated with music production. By framing music production as a process of continuous intra-action, the NIME field can explore new theoretical insights into how music is negotiated and enacted within increasingly entangled human-technology environments. This opens new opportunities for rethinking the boundaries of creative collaborations in music productions with DMIs.

It is equally important to note at this point that the concept of mutual incorporation I define here in this article as part of the musical intra-action framework, differs somewhat from the approaches in the literature that describes mutual incorporation as the seamless integration of instruments into the musician's body and mind, where the instrument becomes an extension of the musician and functions transparently within the sense-making activities (Geeves & Sutton, 2014; Nijs et al., 2013; Schiavio & De Jaegher, 2017; Thompson & Stapleton, 2009). It is argued that for an instrument to be considered incorporated, it must operate transparently, meaning it does not interrupt the musician's interaction (Thompson & Stapleton, 2009). In this approach, transparency enables the instrument to be used effortlessly, functioning as a natural extension of the body. For example, in this view of mutual incorporation, a violinist seamlessly incorporates their instrument into their playing, such that the bow and strings feel like extensions of their own body. The violin responds intuitively to the musician's gestures, allowing for expressive performances in which all musicians engage in a participatory sense-making process, where musicians' interactions shape the music in real-time.

This approach primarily considers human agency, looking at how musicians influence each other through

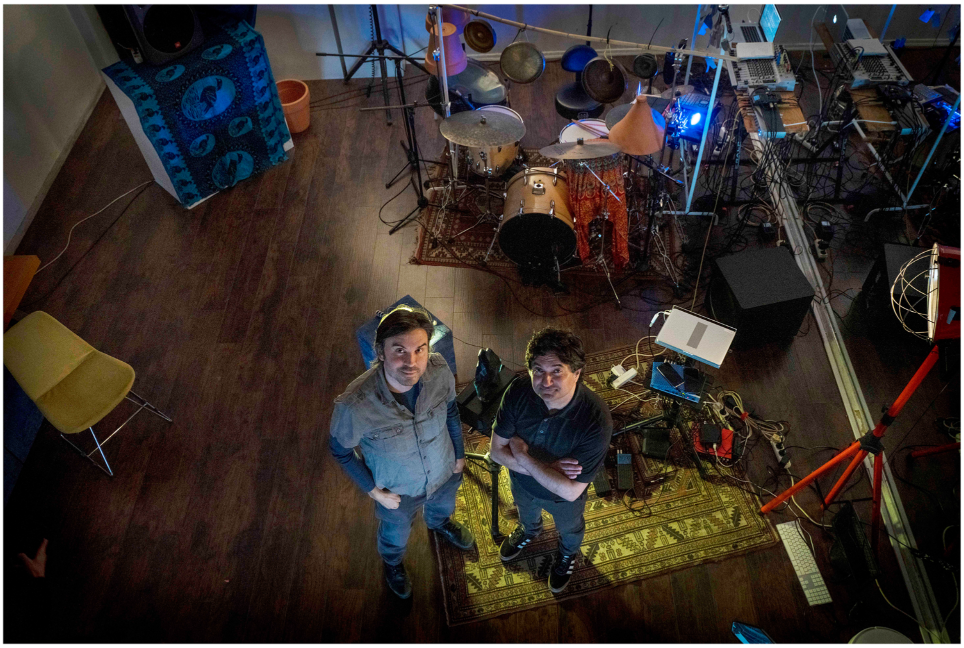

Figure 1. The studio sessions involved musicians engaging in improvisational and compositional practices, experimenting with an AI musical instrument to investigate dynamic exchanges and the emergence of new sonic possibilities.

embodied interaction. It takes individuals as the starting point who then engage in a mutual process of sense-making, focusing on their interactional processes. The role of non-human entity is not the central focus, although they might still play a passive, background role in the ways they incorporate in interaction. It focuses on how musicians co-create meaning through their interactions and ongoing engagement with other musicians.

In the concept of mutual incorporation in musical intra-action, I view materials – whether technological or otherwise – as having their own agency. Non-human entities, such as technology, objects, and physical phenomena, play an equally important role in shaping outcomes and meaning, emphasising an entangled agency. Therefore, I define mutual incorporation as a complex, reciprocal relationship between musicians and technological entities, wherein music production becomes a co-creative process – a form of collaborative creativity that arises from the entanglement of human and non-human entities.

Studio sessions with AI-terity

Together with musician, composer, and artist Berke Can Özcan[6], we had the chance to explore a new range of musical possibilities through generative AI technologies during organised studio sessions in Istanbul in March 2022 (Figure 1). The studio sessions quickly became a kind of practice, a constant form of play that opened up new musical challenges beyond the ones we introduced in our earlier practice of making music. These studio sessions with an AI musical instrument have led us to explore music production, engaging with ever-shifting timbre changes that emerge within a multi-dimensional latent space. Laten spaces in deep learning models reveal hidden correlations between audio features and creative possibilities, leading to unexpected musical outcomes (Tahiroglu & Wyse, 2024).

Özcan mentioned in one of the recording sessions that it was as if we were thrown into the space of the musical universe with continuously transforming cluster of sounds, at the same time, facing with the challenge of forming a new transitional relationship between us and the AI-terity[7] (Figure 2). We had a way of composing and performing in this unique situation in which we have been re-interpreting and re-framing our own experience. Re-defining the possibilities and finding the right means of exploring what we were familiar and what we were not, was for us a way of making sense of the new sounding practices in the studio sessions.

To explore this collaborative creativity further, I will elaborate on the interview I conducted with Özcan after

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[6] Berke Can Özcan is a musician, performing artist, producer born and based in Istanbul. Studied music at the university. Founded the record label titled "Who Are We Who We Are". He has formed bands and performed, recorded and toured with many international musicians.

[7] AI-terity is an AI musical instrument that provides a sculpture like gestural interface to navigate in realtime in a GAN latent space (Tahiroğlu et al., 2020a).

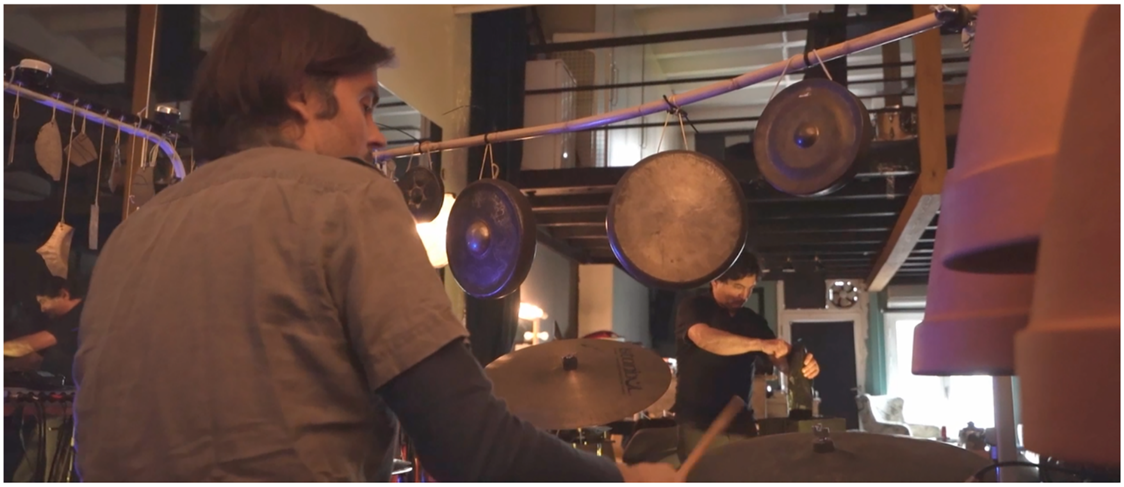

Figure 2. Özcan's setup during the studio sessions included percussive drum loop modulations, a traditional drum set, everyday objects, and various percussive instruments collected from around the globe.

our live recording studio sessions. The interview questions aimed to focus on his personal experience and observations, as well as his subjective reflections on the collaboration. I specifically asked the following questions: In what ways did the AI-terity instrument influence the music during the sessions? Were there any challenges or advantages you noticed when collaborating with the AI-terity instrument compared to a musician collaborator? And in what ways did the AI-terity instrument contribute to the sense of collective creativity during the sessions?

Özcan initially had low expectations, comparing AI's capabilities to 'General MIDI' and expecting that the machine's sounds would be uninspiring and difficult to operate. However, he quickly found himself drawn into the new possibilities offered by AI-terity. The initially 'uncanny' sounds began to make sense, suggesting that the instrument was capable of surprising and engaging him. The unfamiliar look of AI-terity, resembling 'a visitor from another planet,' made Özcan focus intensely on listening, as he could not predict the sounds AI-terity would produce. The instrument often evoked primal, rhythmic responses from him ('caveman drumming'), which contrasted with his expectation of engaging with more textural elements of the drum kit. Özcan noted that AI-terity was not entirely separate from human musician interaction. In view of its AI nature, AI-terity brought out the 'non-human' aspect in the collaboration, suggesting a unique form of interaction that was different from working with human musicians. Özcan described his relationship with AI-terity as a partnership, characterised by a special mediated way that was both inspiring and filled with potential. AI-terity contributed to a sense of collective creativity by enabling Özcan to reshape and transform ever-changing sounds into musical forms, demonstrating its role in facilitating dynamic, ongoing co-creation.

Initially sceptical, Özcan discovered that AI-terity expanded his creative scope and challenged his preconceptions. The instrument's, in one-way, unpredictable nature demanded an intense focus on listening, advancing a deeper engagement with the creative process. AI-terity's influence extended beyond sound production; it reshaped Özcan's approach to music-making in these sessions, highlighting the possible social connections between musician and machine. While the interview presents a subjective view, this supports the argument that music production is not merely the result of individual agency but a socially embedded process involving the mutual incorporation of all participants.

Conclusion

To conclude, this article aims to deepen our understanding of the collaborative act of music production by emphasising the mutual and interdependent nature of relationships between musicians and technologies. In this article, I take an alternative approach by exploring the entanglement of musicians and technologies in music production from a musical intra-action perspective. Furthermore, I define this perspective as mutual incorporation: a reciprocal relationship between musicians and technologies, where both entities mutually influence, shape, and transform one another throughout the music production process. The overall discussion here explores how the concept of musical intra-action leads us to think further about the co-evolving roles of human and non-human entities in music practices. I intended to support my investigation through the outcome of the workshop and the subjective observation of our studio sessions.

Through the notion of musical intra-action, it becomes clear that music productions are inherently linked to the processes in which human and non-human entities co-create them and to the outcomes that emerge from these collaborative practices, emphasising that they cannot be separated from mutual entanglement – the constant change and becoming of music. Therefore, in the context of music production, there are strong reasons to argue that dependent and interdependent relationships are crucial for achieving a mutually beneficial musical experience. The arguments on musical intra-action presented in this article are intended to encourage further discussion about the role of interdependent, co-evolving human and non-human relationships in music practices. Musical intra-action involves both a phenomenon and interconnected dynamics, creating opportunities for further exploration across diverse collaborative music practices. Furthermore, this notion of co-evolving entities opens new perspectives on the design and evaluation of *New Interfaces for Musical Expression*, which should be tailored to comprise the emerging properties of the intra-actional music experience.

Notes

1. New Interfaces for Musical Expression (NIME) is an established and interdisciplinary research field that has been exploring the development and use of advanced music technologies for musical expression since 2001. It focuses on designing, evaluating, and applying new musical instruments and interfaces, often integrating knowledge and practices from fields such as human-computer interaction, computer music, and interface design.
2. These ensembles in a NIME context often include non-traditional, custom-designed and technologically advanced musical instruments that expand the possibilities of musical performance.
3. Fuchs and De Jaegher (2009) introduced the concept of Participatory Sense-Making that refers to the co-creation of meaning through social interaction and mutual engagement. While in their framework, sense-making is not seen as an isolated activity limited to an individual's cognitive process but rather as an inherently interactive phenomenon, it still focuses more narrowly on the social and interactive aspects of human cognition and sense-making processes. Barad's notion of intra-action extends this idea to a broader level, involving both human and non-human agents and challenging traditional notions of independent entities (Barad, 2007).
4. The text in the parenthesis belongs to me, this is to spot the context that the participants were refering to in the workshop.
5. The text in the parentheses belongs to me.
6. Berke Can Özcan is a musician, performing artist, producer born and based in Istanbul. Studied music at the university. Founded the record label titled "Who Are We Who We Are". He has formed bands and performed, recorded and toured with many international musicians.
7. AI-terity is an AI musical instrument that provides a sculpture like gestural interface to navigate in realtime in a GAN latent space (Tahiroğlu et al., 2020a).

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