DrumXRoll: Exploring XR Piano Roll in Teaching Drum Improvisation

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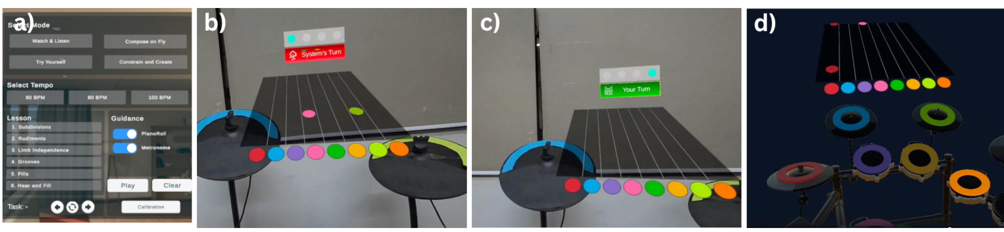

Fig. 1. **Figure X. Overview of the `DrumXRoll` XR drum-improvisation system**. The interface includes a mode and tempo selection panel (a), a passthrough-based XR view displaying the slanted piano-roll guidance and turn-taking cues during System and User turns (b)(c), and a full-3D virtual drum kit with color-coded pads aligned to the piano-roll notes (d).

Drum improvisation is an essential skill in ensemble performance, yet traditional learning methods often rely on fragmented materials and lack immersive, hands-on guidance. These approaches frequently emphasize theory more than real-time creative decision-making, leaving a gap between knowledge and performance. This study explores how extended reality (XR) can address this gap by providing real-time visual cues mapped onto an electronic drum set, guiding drummers as they learn foundational patterns and develop improvisational fluency. A structured learning protocol is introduced, consisting of two phases: (1) solo fundamental training focused on subdivisions, rudiments, and limb independence, and (2) full-band immersion using backing tracks to simulate live performance contexts. The protocol remains genre-agnostic to support adaptability across musical styles, with genre-specific nuances refined through expert input. The study aims to inform the design of technology-supported music learning tools that enhance accessibility, creativity, and performer engagement.

CCS Concepts: • **Human-centered computing → Ubiquitous and mobile computing systems and tools**; • **Applied computing → Interactive learning environments**.

Additional Key Words and Phrases: Drum Improvisation, Extended Reality, Learning Protocol, Piano Roll Visualizations, Music Education

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1 Introduction

Drumming is a deeply embodied musical practice that requires learners to synchronize multiple limbs, maintain consistent timing, and respond musically in real time. Unlike melodic instruments that follow pitch-based structures, the drum set demands a highly physical form of cognition where rhythmic precision must be paired with coordinated motor execution across hands and feet. For beginners, improvisation introduces an additional layer of complexity. Rather than following a fixed beat, score, or instructional video, improvising requires the ability to internalize rhythmic foundations, recall and combine learned patterns, apply them flexibly, and make moment-to-moment creative decisions. Traditional learning tools such as video tutorials, method books, or static notation can support technical development, but they provide limited scaffolding for real-time responsiveness and creative exploration, which are essential to improvisation.

Recent advances in extended reality (XR) have opened new opportunities for embodied music learning, enabling visual augmentation, adaptive feedback, and immersive interaction. Prior XR systems have demonstrated benefits in rhythm reading, piano roll visualization, and introductory percussion tasks. However, most existing work focuses on melodic instruments or on foundational timing exercises, and very few systems target drum improvisation, where timing accuracy, limb independence, pattern vocabulary, and creative spontaneity must be learned together. There is a need for tools that integrate real-time cueing with meaningful opportunities for creative play.

DrumXRoll addresses this gap by introducing an XR piano roll interface that projects falling visual cues onto a physical electronic drum set using the Meta Quest 3 mixed reality capabilities. Developed through co-design sessions with experienced drummers, the system provides an interactive learning environment that guides beginners from structured observation toward progressive creative expression. Specifically, this work contributes:

- An XR-based piano roll system for drumming that aligns falling cues to physical drums to assist timing, pattern learning, and improvisation.
- A four-mode improvisation-oriented learning framework integrating observation, guided practice, composition, and constrained creativity.
- Co-designed interaction and visualization techniques informed by expert drummers' insights on spatial layout, cue clarity, and rhythmic pedagogy.
- Early empirical findings from a pilot study showing improvements in timing certainty, rhythmic recall, and improvisation confidence.

2 Background and Related Work

Music learning literature highlights the importance of experiential, pattern-based, and embodied approaches for developing musical expertise. These qualities are especially critical for drummers, who must coordinate multiple limbs, internalize rhythmic structures, and maintain precise temporal control while performing [9, 22, 23]. From a broader cognitive perspective, theories of embodied cognition and social learning emphasize that musical skills emerge through situated, bodily, and observational practice rather than through abstract knowledge alone [3, 25]. Traditional learning methods provide exposure to rhythmic patterns through repetition, imitation, or notation, but they offer limited support for the real-time decision making required in improvisation. Without interactive or adaptive feedback, beginners often struggle to transition from playing fixed sequences to generating spontaneous rhythmic ideas [1, 5, 6, 19].

Extended Reality (XR) has emerged as a promising avenue for enhancing music education by providing visual augmentation, adaptive guidance, and immersive learning environments [11, 14? ?]. Prior XR and mixed reality systems have explored piano-roll visualisation, projected guidance, and multimodal feedback to support foundational rhythmic and melodic skills [10, 12, 18? ?]. Augmented and mixed reality instruments such as augmented pianos and drum kits have shown that spatially aligned cues can improve engagement, timing accuracy, and user experience during practice [11, 13, 16, 20, 26]. These visual cueing systems can support rhythm comprehension, reduce cognitive load, and foster learner motivation, but most work focuses on melodic instruments or basic rhythm execution rather than improvisation.

Drumming presents unique pedagogical challenges that differentiate it from other musical domains. Successful drumming requires motor independence across hands and feet, fine microtiming control, and the ability to manipulate rhythmic motifs rather than pitch-based structures [8, 22, 23]. Prior AR and MR drum studies demonstrate that visual feedback can enhance timing accuracy, groove stability, and limb coordination [13, 15, 20, 26]. Despite these benefits, existing systems typically focus on discrete tasks such as hit detection or timing correction, without supporting the broader creative processes involved in generating, varying, and recombining rhythmic ideas during improvisation.

DrumXRoll extends this body of work by applying XR falling-cue visualization specifically to drum improvisation learning. It draws on augmented piano and improvisation systems that structure learning through staged, visually supported modes [10–12] and on mixed reality drum learning tools that emphasize spatial alignment and multimodal feedback [16, 20, 26]. Our system integrates visual, embodied, and creative training in a unified environment that aligns real-time cues with a physical drum set. Through its mixed reality interface and four-mode learning workflow, DrumXRoll supports not only timing and rhythm recall but also the gradual development of improvisational confidence and expressive decision making.

3 The `DrumXRoll` System

DrumXRoll is implemented in Unity and deployed on the Meta Quest 3, utilizing the device's mixed reality passthrough capabilities to overlay falling piano roll cues directly onto a physical electronic drum set. This integration allows learners to view real-world drum components while engaging with virtual guidance elements in an immersive environment. The system operates through three tightly integrated layers: the XR Visual Layer, the Input Layer, and the Lesson Management Layer. Together, these components create an interactive learning experience that supports timing accuracy, rhythmic pattern acquisition, and improvisational development.

3.1 XR Visual Layer

The XR Visual Layer provides the core visual augmentation that characterizes DrumXRoll. Falling color-coded bars represent upcoming drum strikes for each component of the drum kit, including the snare, kick, toms, hi-hats, and cymbals. These cues are positioned in three-dimensional space so that they appear to descend toward the corresponding physical pads. As the cues fall, they follow a vertical timeline consistent with traditional piano roll representations, giving learners a clear and intuitive visualization of rhythmic timing. When the cues reach the strike zone, they align precisely with the real drum surfaces, allowing users to anticipate and execute hits with improved accuracy. This spatial alignment ensures that visual information reinforces embodied action, making the learning process both intuitive and immersive.

3.2 Input Layer

The Input Layer establishes communication between the XR interface and the physical drum kit. DrumXRoll integrates an Alesis Nitro electronic drum set through a MIDI-to-USB connection, enabling low-latency transmission of drum hits into the Unity environment. Each detected hit is time-stamped and mapped to its corresponding drum component. The system evaluates the accuracy of each hit by comparing the user's timing against the expected cue position. Feedback is then provided visually through indicators such as color changes, hit markers, or timing offsets. This real-time feedback loop allows learners to immediately understand their performance, supporting gradual improvement in timing and consistency.

3.3 Lesson Management Layer

The Lesson Management Layer structures the learning experience through four interactive modes that scaffold the learner from passive observation to active improvisation. This staged approach is inspired by prior work on augmented piano and improvisation training, which emphasizes progression from modelling and imitation toward guided variation and constrained creativity [10–12]. The modes are designed to support different stages of rhythmic development and to accommodate a wide range of learner needs.

3.3.1 Watch & Listen. In this demonstration-oriented mode, learners observe falling cues synchronized with audio playback. The goal is to familiarize users with rhythmic sequences, subdivisions, and patterns before attempting to play them. This mode emphasizes passive exposure and listening, enabling learners to build initial mental models of the patterns, consistent with observational and modelling-based learning strategies [3, 9].

3.3.2 Try Yourself. In this active practice mode, falling cues appear as in the demonstration phase, but the user performs the patterns in real time. The system evaluates each hit and provides correctness indicators, including timing deviations or missed notes. Similar to prior XR music tutors that combine visual guidance with performance feedback [10, 18, 26], this mode focuses on developing accuracy, consistency, and internal timing.

3.3.3 Compose on the Fly. This improvisation-oriented mode allows learners to perform freely without predetermined patterns. As the user plays, the system records the sequence of hits and generates dynamic visualizations that mirror the improvised rhythm. This feature enables learners to reflect on their creative output, explore rhythmic ideas, and gain confidence in generating spontaneous patterns, echoing design goals in augmented improvisation systems such as ImproVISe [12].

3.3.4 Constrain & Create. In this structured improvisation mode, learners are given specific boundaries or constraints to guide their creative exploration. Examples include restricting improvisation to certain drum components, limiting the type of rhythmic subdivisions, or requiring patterns that use only two limbs. This approach parallels constraint-led coaching and improvisation pedagogy, where carefully chosen constraints shape exploration and support the emergence of functional, adaptable skills [4, 12, 21]. These constraints encourage deliberate experimentation and help learners develop improvisational fluency while maintaining musical coherence.

4 Design and Concept

The design of DrumXRoll was informed by a co-design workshop conducted with four experienced drummers whose playing backgrounds ranged from three to nine years. The goal of the workshop was to understand how extended reality can effectively support beginner drum improvisation and to align the system with real-world drumming practice, identity, and learning trajectories [22, 23].

To gather detailed insights, the workshop consisted of seven structured activities that explored key areas of drumming pedagogy and interaction design. These activities examined lesson sequencing, rudiment selection, limb independence development, genre suitability, groove and fill selection, improvisation assessment, and user interface layout within an XR environment. The resulting discussions and observations provided a foundation for shaping the interaction model, visual design, and learning progression implemented in DrumXRoll.

4.1 Foundations and Skill Progression

A central theme across participant feedback was the importance of establishing foundational skills before introducing creative tasks. Participants emphasized that subdivisions, basic rudiments such as the single stroke, double stroke, flam, flam accent, and single paradiddle, and early development of limb independence form the essential groundwork for improvisation, consistent with established percussion pedagogy [9] and motor learning work highlighting the role of repetition and variation [7, 17]. The workshop highlighted that improvisational fluency emerges only when learners have internalized these fundamental techniques, reinforcing the need for DrumXRoll to present structured, foundational lessons prior to more exploratory activities [5, 19].

4.2 Genre Selection and Rhythmic Vocabulary

When considering the musical context for beginner improvisation, the participants identified the pop genre as the most appropriate foundation. They noted that pop offers a wide rhythmic range, accessible patterns, and predictable structures that support learning, echoing discussions of groove-based microrhythm and stylistic practice in contemporary drumming research [8, 23]. This also aligns with practitioner-oriented accounts of the drummer's role in popular and jazz idioms [2, 24]. Compared to genres with more complex rhythmic variations, pop was viewed as flexible, beginner-friendly, and highly compatible with scaffolded improvisation. This insight guided the system's default genre selection and influenced the design of practice patterns and backing tracks.

4.3 Visual Cue Design and Occlusion Management

Visual cues emerged as one of the most critical elements in the XR environment. Participants expressed a preference for falling cues that remain clearly visible without obstructing the drummer's view of the physical drums. Similar concerns about cue placement, colour coding, and visual clarity have been reported in augmented piano and drum systems, where poorly designed overlays can increase cognitive load or interfere with motor execution [11, 13, 20, 26]. To address this, participants recommended placing the cues slightly above the rims of the drum surfaces and using distinct colour-coding combined with subtle glow effects. This design reduces visual clutter, supports quick identification of drum targets, and preserves the learner's peripheral awareness, all of which contribute to more intuitive cue tracking during performance.

4.4 Supporting Limb Independence

The workshop consistently identified limb independence as one of the most challenging skills for beginners. Participants noted that learners often struggle to coordinate simultaneous movements of hands and feet, especially when performing patterns with multiple subdivisions, aligning with prior accounts of drummers' motor and identity development [22, 23]. They suggested that XR cues should highlight the relationships between limb movements, making it easier for learners to anticipate interactions between drum components. Participants also recommended allowing slowed-down or loopable cue sequences to help users practice difficult segments repeatedly until comfortable, which is consistent with findings on practice variability and micro-looping in motor learning [7, 17]. These insights directly influenced the system's cue timing options and practice mode features.

4.5 Scaffolding Improvisation Through Constraints

Participants agreed that improvisation should not be introduced as a fully open task for beginners. Instead, they advocated for structured constraints that gradually guide learners toward creative expression. Examples included limiting improvisation to specific drum components, restricting rhythmic subdivisions, or assigning patterns that require only two-limb coordination. This perspective aligns with constraint-led coaching and improvisation frameworks that emphasise shaped, game-like tasks rather than isolated "basics-first" drills [4, 21] and with recent augmented improvisation systems that encode improvisation exercises as sequences of constrained, visually guided tasks [12]. These constraints were seen as productive boundaries that encourage learners to explore rhythmic possibilities while avoiding cognitive overload. This perspective strongly shaped the design of the Constrain & Create mode in DrumXRoll.

4.6 Spatial Alignment and Embodied Interaction

Accurate spatial alignment between virtual cues and physical drum components was emphasized as essential for maintaining an intuitive learning experience. Participants stressed that cues should reflect the real physical positions of the drum set rather than forcing learners into unfamiliar spatial arrangements. Prior work on augmented instruments has similarly highlighted that misaligned overlays can break embodied correspondence and hinder the formation of stable sensorimotor mappings [11, 14, 20]. Proper alignment supports embodied learning by reinforcing natural stick trajectories and muscle memory. As a result, DrumXRoll calibrates cue placement to the user's actual drum configuration, ensuring that the XR overlay aligns seamlessly with physical movements.

Collectively, these design insights informed the spatial arrangement of cues, the timing and pacing of visual guidance, the progression of lesson content, and the structure of the system's four learning modes. The co-design process ensured that DrumXRoll aligns with real drumming practices and addresses the specific challenges faced by beginners learning improvisation.

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5 Early Findings

We conducted an early pilot evaluation of DrumXRoll with $N = 4$ beginner to novice-intermediate drummers. Each participant engaged in a 20–30 minute session that introduced all four learning modes of the system: Watch & Listen, Try Yourself, Compose on the Fly, and Constrain & Create. The goal of this preliminary evaluation was to observe how mixed reality guidance influences early-stage skill development in timing, pattern acquisition, limb coordination, and improvisational confidence. Although exploratory in nature, the results provide initial evidence that DrumXRoll supports several aspects of rhythmic learning and improvisational engagement.

5.1 Quantitative Indicators

The collected performance data indicate measurable improvements across three key dimensions of rhythmic training. First, participants demonstrated enhanced *timing stability*, as shown by reduced onset deviation after transitioning from Watch & Listen to Try Yourself. The combination of visual anticipation and immediate correctness feedback allowed learners to synchronize their hits more consistently with the expected cue positions.

Second, participants showed increased *subdivision awareness*. With falling cues present, learners recognized 8th- and 16th-note patterns more quickly, reflecting improved understanding of rhythmic density and temporal spacing. This suggests that the XR representation helped externalize rhythmic structure in a perceptually accessible format.

Third, we observed gains in *pattern recall*. Participants were better able to reproduce short grooves after visually experiencing them in Watch & Listen, indicating that the piano roll visualization supported short-term memory for rhythmic sequences. These quantitative indicators collectively suggest that DrumXRoll can accelerate foundational skill acquisition during early learning stages.

5.2 Qualitative Themes

Post-session interviews provided additional insights into how learners perceived the XR environment and how it shaped their behavior during practice. Three major themes emerged from these discussions.

Cues Reduce Uncertainty. Participants consistently reported that the falling cues helped them "know what is coming next," particularly during fills and transitions. This sense of anticipation reduced hesitation and allowed learners to engage with the rhythm more fluidly. Beginners described the visual timeline as reassuring, providing a clear structure that minimized guesswork.

Visual Alignment Supports Limb Independence. Many learners highlighted that seeing separate cue streams for hands and feet reduced confusion when coordinating multiple limbs. The spatial alignment of cues with the physical drum pads helped participants understand how limb movements relate to specific drum components. This was especially beneficial for patterns requiring independent kick and snare activity.

Improvisation Confidence Increased. Participants noted that Compose on the Fly and Constrain & Create encouraged them to experiment freely without fear of making mistakes. The mixed reality environment was described as "low pressure," providing a safe space for trying new rhythmic ideas. Learners expressed that improvisation felt more approachable when guided by visual structure and optional constraints.

5.3 Design Implications

The pilot study highlighted several design implications for refining DrumXRoll and for informing future XR-based percussion learning systems. First, beginners benefit significantly from *preview-style cues*, especially for anticipating drum fills or sudden rhythmic changes. Maintaining a clear forward-looking visual timeline appears essential for reducing cognitive load.

Second, improvisation features should employ *manageable constraints* to avoid overwhelming new learners. Limiting the number of active limbs or restricting rhythmic density helps learners build creative fluency gradually. Participants gravitated toward constrained tasks as stepping stones toward more open-ended improvisation.

Third, learners expressed a preference for *simple cue aesthetics*, including clean bar-shaped cues, minimal glow, and strong, distinct color mappings. Overly stylized visuals tended to distract rather than assist.

Finally, XR-based drum training should emphasize *repeatable micro-loops* that allow learners to rehearse difficult segments in short, focused bursts. This approach aligns with established motor-learning principles and was strongly supported by participant feedback.

Overall, the early findings suggest that DrumXRoll effectively supports foundational rhythmic learning and fosters creative engagement in improvisation. These insights will inform subsequent iterations of the system and guide the design of the full-scale user study.

6 Conclusion

In this paper, we presented `DrumXRoll`, an extended reality drum training system that overlays a piano roll style visualization onto a physical electronic drum kit. By combining mixed reality falling cues, low-latency input from an Alesis Nitro kit, and a four-mode learning workflow, the system aims to support beginners as they move from following fixed patterns to exploring improvisation.

Insights from a co-design workshop with experienced drummers shaped key aspects of the system, including foundational focus on subdivisions and rudiments, pop-based practice material, minimal-occlusion cue layouts, and constraint-based improvisation tasks. An early pilot with beginner to novice-intermediate drummers suggested improvements in timing stability, subdivision awareness, and confidence in improvising within the XR environment.

Future work will involve larger and longer-term evaluations, exploration of additional genres and difficulty adaptations, and further refinement of feedback and assessment mechanisms. Our findings point to the potential of XR piano roll visualizations to bridge technical skill building and creative drum improvisation in a single, integrated learning experience.

References

[1] Philip Alperson. 1984. On musical improvisation. *The Journal of Aesthetics and Art Criticism* 43, 1 (1984), 17–29.

[2] ArtistWorks. n.d.. Jazz Drumming Origins. https://my.artistworks.com/blog/jazz-drumming-origins Accessed: 2025-03-22.

[3] Albert Bandura and Richard H Walters. 1977. *Social learning theory*. Vol. 1. Prentice Hall, Englewood Cliffs, NJ.

[4] Bruce Ellis Benson. 2021. Taking Responsibility by Letting Go: The Improvisation of Responding to the Call. In *Philosophy of Improvisation*. Routledge, 87–100.

[5] Pauline Black. 2023. Jazz and improvising: experiences, attitudes and beliefs of United Kingdom (UK) secondary school music teachers: listening for gender. In *Frontiers in Education*, Vol. 8. Frontiers Media SA, 1084761.

[6] Glen Alan Brumbach. 2017. *The effects of practice-based and theoretical-based pedagogical approaches on jazz improvisation and performance achievement by high school musicians*. Ph. D. Dissertation. University of Maryland, College Park.

[7] Carla Caballero, David Barbado, Manuel Peláez, and Francisco J Moreno. 2024. Applying different levels of practice variability for motor learning: More is not better. *PeerJ* 12 (2024), e17575.

[8] Guilherme Schmidt Câmara. 2021. Timing is everything... or is it? Investigating timing and sound interactions in the performance of groove-based microrhythm. (2021).

[9] Gary Cook. 1988. *Teaching percussion.* Schirmer Books.
[10] Jordan Aiko Deja. 2022. Piano learning and improvisation through adaptive visualisation and digital augmentation. In *Companion Proceedings of the 2022 Conference on Interactive Surfaces and Spaces.* 41–45.
[11] Jordan Aiko Deja, Sven Mayer, Klen Čopič Pucihar, and Matjaž Kljun. 2022. A survey of augmented piano prototypes: Has augmentation improved learning experiences? *Proceedings of the ACM on Human-Computer Interaction* 6, ISS (2022), 226–253.
[12] Jordan Aiko Deja, Sandi Štor, Ilonka Pucihar, Klen Čopič Pucihar, and Matjaž Kljun. 2024. Teach me how to ImproVISe: co-designing an augmented piano training system for improvisation. *arXiv preprint arXiv:2402.02999* (2024).
[13] Torin Hopkins, Suibi Che Chuan Weng, Rishi Vanukuru, Emma A Wenzel, Amy Banic, Mark D Gross, and Ellen Yi-Luen Do. 2022. Ar drum circle: Real-time collaborative drumming in ar. *Frontiers in Virtual Reality* 3 (2022), 847284.
[14] David Johnson. 2019. *MusE-XR: musical experiences in extended reality to enhance learning and performance.* Ph. D. Dissertation.
[15] Mladen Konecki. 2023. Adaptive drum kit learning system: Impact on students' learning outcomes. *Int. J. Inf. Educ. Technol* 13 (2023), 1534–1540.
[16] Yongjun Kweon, Sunmyeong Kim, Byounghyuk Yoon, Taeyang Jo, and Changhoon Park. 2018. Implementation of educational drum contents using mixed reality and virtual reality. In *HCI International 2018–Posters' Extended Abstracts: 20th International Conference, HCI International 2018, Las Vegas, NV, USA, July 15-20, 2018, Proceedings, Part II 20.* Springer, 296–303.
[17] Guilherme M Lage, Herbert Ugrinowitsch, Tércio Apolinário-Souza, Márcio Mário Vieira, Maicon R Albuquerque, and Rodolfo Novellino Benda. 2015. Repetition and variation in motor practice: a review of neural correlates. *Neuroscience & Biobehavioral Reviews* 57 (2015), 132–141.
[18] Will Molloy, Edward Huang, and Burkhard C Wünsche. 2019. Mixed reality piano tutor: A gamified piano practice environment. In *2019 International conference on electronics, information, and communication (ICEIC).* IEEE, 1–7.
[19] Martin Norgaard, Laura A Stambaugh, and Heston McCranie. 2019. The effect of jazz improvisation instruction on measures of executive function in middle school band students. *Journal of Research in Music Education* 67, 3 (2019), 339–354.
[20] James Pinkl, Julián Villegas, and Michael Cohen. 2024. Multimodal Drumming Education Tool in Mixed Reality. *Multimodal Technologies and Interaction* 8, 8 (2024), 70.
[21] Ian Renshaw and Brendan Moy. 2018. A constraint-led approach to coaching and teaching games: Can going back to the future solve the 'they need the basics before they can play a game' argument? *Ágora para la Educación Física y el Deporte* 20, 1 (2018), 1–26.
[22] Gareth Dylan Smith. 2011. *'I drum therefore I am': a study of kit drummers' identities practices and learning.* Ph. D. Dissertation. Institute of Education, University of London.
[23] Gareth Dylan Smith. 2016. *I drum, therefore I am: Being and becoming a drummer.* Routledge.
[24] Jazz Styles. 2024. Drummer's Role. https://jazzstyles.net/drummers-role/ Accessed: 2025-03-22.
[25] Margaret Wilson. 2002. Six views of embodied cognition. *Psychonomic bulletin & review* 9 (2002), 625–636.
[26] Tetsuo Yamabe, Hiroshi Asuma, Sumire Kiyono, and Tatsuo Nakajima. 2011. Feedback design in augmented musical instruments: A case study with an ar drum kit. In *2011 IEEE 17th International Conference on Embedded and Real-Time Computing Systems and Applications*, Vol. 2. IEEE, 126–129.