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Laptop Orchestra: A Model Postdigital Resonant Educational Space

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Abstract

This study discusses the Postdigital Laptop Ensemble at the University of Siegen (PULSE) as a model postdigital resonant educational space. Situated within postdigital discourse, the course treats laptops and portable digital devices as musical instruments within a hybrid classroom, fostering collaborative, creative, and embodied learning experiences. Drawing on Hartmut Rosa's theory of *resonance*, this study examines how spatial design and technology-mediated interactions in PULSE cultivate a *Resonanzraum*—a dynamic space of mutual transformation. Through qualitative methods, including (1) a student survey, (2) autoethnographic reflections, and (3) an analysis of audio-visual data, we identify six themes that contribute to the emergence of resonance: (1) spatial comfort, (2) collaboration, (3) spatial constraints/affordances, (4) technology-mediated agency, (5) iterative learning, and (6) future classroom implications. The findings suggest that PULSE creates an inclusive postdigital educational space that enhances student agency and multimodal engagement. However, scalability challenges, such as resource disparities, highlight the need for adaptive implementations. This study aims to bridge *resonance* and postdigital research, proposing PULSE as a model for designing equitable, sustainable, and participatory learning spaces that align with evolving pedagogical demands.

Keywords Postdigital education · Resonant pedagogy · Space · Agency · Creativity · Laptop orchestra

Introduction

As digital technologies increasingly permeate education, they are shifting from supplementary tools to embedded, often invisible components of learning environments—reflecting a postdigital paradigm (Knox 2019; Fawns 2019; Jandrić and Knox 2022; Lindberg and Johansson 2023; Forsler et al. 2024). This complicates the spatial dimensions of learning by (re)shaping the very concept of space, as digital technologies transform spatial relations into open, fluid, and continuously evolving configurations (Mütterlein and Fuchs 2019; Knox 2019; Atherton and Wang 2020; Jandrić and Knox 2022; Jopling 2023; Otrel-Cass 2023; Wilde et al. 2024). The postdigital classroom is a complex spatial assemblage in which social, material, and social dimensions continuously intersect

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and reshape teaching and learning (Sinclair 2023; Jopling 2023; Macgilchrist et al. 2024; Forsler et al. 2024).

Within this context, a central concern emerges: while digital technologies promise to offer enhanced connectivity and multimodal engagement, they also risk introducing new forms of alienation where data-intensive, mediated learning environments can fragment experience and marginalize participation (Fawns 2019). This paradox raises a critical pedagogical question: how can educators design technologically mediated learning spaces that facilitate resonant, relational, and participatory experiences?

Resonant pedagogy (*Resonanzpädagogik*), as conceptualized by Rosa and Endres (2016), offers a compelling framework for addressing this challenge. Resonance is characterized by reciprocal engagement between individuals and their environments, fostering mutual transformation through meaningful encounters (Rosa and Endres 2016). In educational spaces, resonance takes shape as a dynamic, affective relationship between students, teachers, and learning materials, counteracting the often alienating effects of technological acceleration (Rosa 2019).

This paper investigates how digital technologies not only shape the spatial architecture of postdigital learning environments but also mediate the conditions under which resonance can—or cannot—emerge. Focusing on the entanglement of technology, space, and pedagogy, we explore how resonant experiences might be supported within classrooms that are increasingly complex, hybrid, and algorithmically structured. Specifically, this study aims to examine the potential of resonant pedagogy in cultivating affective, relational, and co-creative forms of engagement in technologically mediated learning spaces.

We examine these dynamics through the case study of the Postdigital Laptop Ensemble at the University of Siegen (PULSE), a university ensemble and postdigital educational space for teacher training. PULSE reimagines the classroom as a multi-layered environment where physical, digital, and social dimensions converge. Building on foundational models such as the Princeton Laptop Orchestra (PLOrk) (Trueman 2007) and the Stanford Laptop Orchestra (SLOrk) (Wang et al. 2008), PULSE expands the laptop orchestra concept into teacher education, framing digital technologies as co-creative agents in shaping postdigital learning.

By situating PULSE within the discourse of postdigital education (Fawns 2019; Jandrić et al. 2023b; Aitken and Jones 2023; Carvalho and Lamb 2023; Bozkurt 2024; Carvalho et al. 2024; Forsler et al. 2024; Jaldemark 2024; Bissel et al. 2025), this study considers how learning environments can be designed beyond binary distinctions such as online versus offline, physical versus virtual, and human versus machine (see Goodyear et al. 2004). Rather than adopting commercially driven educational technology (EdTech) models that emphasize efficiency and standardization—critiqued in educational research (see Aitken and Jones 2023)—PULSE encourages student agency, critical reflection, and multimodal engagement. The PULSE classroom, augmented by digital interfaces, becomes a hybrid and adaptive environment that facilitates fluid transitions between modes of co-presence (Wilde et al. 2024).

Drawing on qualitative data—including participant surveys, instructor autoethnographic reflections, and audio-visual documentation—we use reflexive thematic analysis (Braun and Clarke 2006; 2022) to examine how students perceive space, presence, and participation within this postdigital learning environment. Our aim is to contribute to ongoing theoretical and empirical discussions on the design of more equitable, sustainable, and resonant educational spaces (White and Wilde 2024; Macgilchrist et al. 2024).

Theoretical Framework

In this study we draw on resonant pedagogy and postdigital education. By integrating these perspectives, we argue that PULSE holds the potential to exemplify a *postdigital resonant educational space*, understood as a site of co-creativity, networked multimodal learning, and embodied collaboration (see White 2025), where digital technologies function as active agents in shaping learning experiences. Postdigital education calls for a (re)evaluation of how learning environments are conceptualized and enacted, as shifts in classroom spatiality actively (re)shape the dynamics of teaching and learning (Fawns 2019). *Resonant pedagogy* (Rosa and Endres 2016) provides a strong framework for understanding how meaningful, relational engagement can be facilitated in digitally mediated spaces.

Resonant Pedagogy: A Framework for Meaningful Learning

Rooted in Rosa's (2019) broader theory of resonance, *resonant pedagogy* (Rosa and Endres 2016) provides a strong framework for understanding how meaningful, relational engagement can be facilitated in digitally mediated spaces. This perspective challenges alienation in modern education and argues that meaningful learning emerges through a dynamic, reciprocal relationship between learners, educators, and their environments. Figure 1 illustrates the 'triangle of resonance' as it operates within a resonant learning space (Rosa 2019).
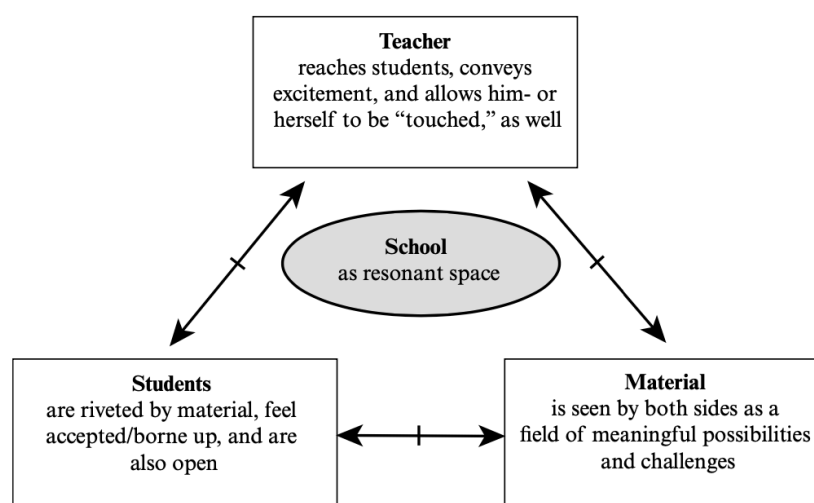
Figure 1. The 'triangle of resonance,' as presented in Rosa's (2019) *Resonance: A Sociology Of Our Relationship To The World.*

We adopt resonant pedagogy as our central analytical framework for investigating the spatial, social, and learning dynamics in PULSE. We use the 'triangle of resonance' to analyze how learners, educators, and the postdigital environment co-create conditions of meaningful engagement. Resonance is an active state of engagement in which learners and their environments affect and transform one another (Rosa and Endres 2016). This perspective critiques the depersonalization and standardization of learning—especially relevant in the digital age—and calls for pedagogies that restore relational depth, emotional attunement, and

mutual responsiveness. Rosa and Endres (2016), outline five key concepts that underpin resonant pedagogy:[1]

1. **Transformation (*Anverwandlung*)** - Learning is a process of deep engagement that alters the learner, true education transforms the self by opening it to the world (p. 16).

2. **Resonance Space (*Resonanzraum*)** - The classroom should be a dynamic space of interaction, where tension, curiosity, and creativity 'crackle' (*knistert*) with engagement (p. 34).

3. **Dispositional Resonance (*Dispositionale Resonanz*)** - As young people pass through the educational space of school, they should be placed in a position that makes them curious about the world, about their life in the world. They should find a way to enter into processes of relating (p. 19).

4. **Self-Efficacy Experiences (*Selbstwirksamkeitserfahrungen*)** - Students must perceive themselves as active participants in their learning, where their actions resonate with the world (p. 54).

5. **World Relationship (*Weltbeziehung*)** - Education should connect learners to broader social and cultural contexts, encouraging them to 'hear the world's call and respond to it' (p. 16).

While resonant pedagogy critiques the standardization of digital education, postdigital theorists emphasize that digital technologies are not inherently alienating; their impact depends on how they shape learning environments (Jandrić and Knox 2022). This study examines how digitally mediated spaces, like PULSE, can enable resonance by supporting spatial conditions for embodied, relational, and meaningful learning.

Postdigital Resonance in Education

While Rosa's (2019) theory of resonance provides a powerful framework for analyzing meaningful human-world relations, the rapid evolution of digital technologies—and their deep entanglement with everyday life—necessitates a theoretical expansion. In educational contexts, where learning increasingly occurs across blended, hybrid, and immersive platforms (Mütterlein and Fuchs 2019) the digital domain must be critically examined (Knox 2019). It constitutes an ontological layer of lived experience (Benyon 2014). This paper draws on the concept of *postdigital resonance* (see Wilde et al. 2024) as a fourth axis[2] within Rosa's framework and situates it as a lens for understanding learning in multi-sited educational environments.

Postdigital resonance foregrounds how learners experience meaningful connection through digital mediation across overlapping material, social, and virtual terrains. This builds on Rosa's axes of social, material, and existential resonance, extending them to account for the *co-presences* and *nested emotional states* (NES)[3] in layered digital-analog lifeworlds (Wilde

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[1] Selected terms and their definitions have been translated and interpreted from the original German by the authors.
[2] Rosa's theory of resonance identifies three primary axes—often referred to as dimensions—of relationality: vertical (spiritual or existential), horizontal (interpersonal or social), and diagonal (material or environmental), encompassing the social, material, and existential spheres of experience (Rosa 2019).
[3] See White and Wilde's (2024) animated schematic diagram, which illustrates the concept of 'Nested Emotional States' (NES) across multiple forms of co-presence. NES refers to the complex entanglement of resonant

et al. 2024; Jandrić and Knox 2022). The postdigital condition is an active structuring force that reconfigures presence, identity, and agency (Wilde et al. 2024). In this context, the digital becomes more than a tool or medium—it becomes a mode of being that shapes learners' capacity for relational engagement.

In education, postdigital resonance emerges when learning spaces are designed to support transformative engagement across modalities. In these environments, students' experiences are shaped by digital technologies and return in changed form, a process Rosa (2019) calls mutual transformation *(Anverwandlung)*. The concept of postdigital resonance (Wilde et al. 2024) contributes to our analysis of PULSE in understanding how learning, identity, and connection are reshaped in postdigital educational spaces. As a critical extension of Rosa's framework, the postdigital axis of resonance allows us to conceptualize meaningful educational experiences that are technologically mediated yet deeply human.

Research Methodology: Qualitative, Reflexive, and Arts-based

We employed a qualitative research design, integrating student feedback from a post-course survey, autoethnographic accounts, and audio-visual recordings to analyze spatial, technological, and pedagogical dynamics. Data was analyzed using reflexive thematic analysis (Braun and Clarke 2006; 2022), with a coding process to identify themes related to resonance and space. This methodology aligns with the exploratory nature of postdigital education research, emphasizing methodological plurality, reflexivity, and emancipatory praxis as central to bridging theory and practice (see Jandrić et al. 2023a).

The PULSE Project

PULSE is an innovative course launched at the University of Siegen in 2023 that focuses on developing musical and digital competencies among pre-service teachers from both music and non-music disciplines. Open to undergraduate and graduate students, PULSE welcomed 17 participants (8 women, 9 men) in its first semester (winter 2023/24) and 12 (6 women, 6 men) in its second semester (summer 2024).

Building on the laptop orchestra as a classroom (see Wang et al. 2008), the semester-long course is structured into four phases: (1) introductory workshops, (2) collaborative compositions, (3) rehearsals, and (4) public performances. Participants use laptops, iPads, and coding environments like Ableton Live,[4] Sonic Pi,[5] Max/MSP,[6] and MusiKraken[7] as musical instruments in networked learning (Booth 2010; Ogborn 2014). The boundaries between physical and virtual spaces are blurred, allowing students to engage in collaborative composition and experimentation beyond the constraints of traditional spatial structures.

The course is open to students with diverse levels of musical and technological proficiency and experience. Technical workshops cover skills such as MIDI programming and sound synthesis, while the composition and rehearsal phases prioritize teamwork and exploratory learning (Sikiaridi and Vogelaar 2009). Students reflect on how digital tools can inform both their artistic and teaching practices. The course concludes with a public showcase, archived

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elements—*affection*, *emotion*, *transformation*, and *unpredictability*—across digital, analog, and hybrid modes of presence.
[4] https://www.ableton.com/
[5] https://sonic-pi.net/
[6] https://cycling74.com/
[7] https://www.musikraken.com/

on the PULSE YouTube channel,[8] positioning PULSE as a hybrid space that integrates musical creativity with pedagogical development.

Reconfiguring the Classroom Space

The PULSE laptop ensemble is treated as a case study of how a postdigital classroom can be designed to facilitate resonance, reimagining the classroom as a dynamic and interactive environment. Rather than following traditional lecture-based models, where students remain sedentary, face the instructor, and engage with technology in isolated or solitary ways—often through headphones or individual screens with minimal peer interaction—the PULSE classroom strives to disrupt these conventions. Instead, it creates an entangled learning ecology (see Carvalho and Lamb 2023) by replacing traditional desks with flexible floor mats that encourage movement, playfulness, and communal interaction, inviting spontaneous exchange and shared leadership (see Figure 2).
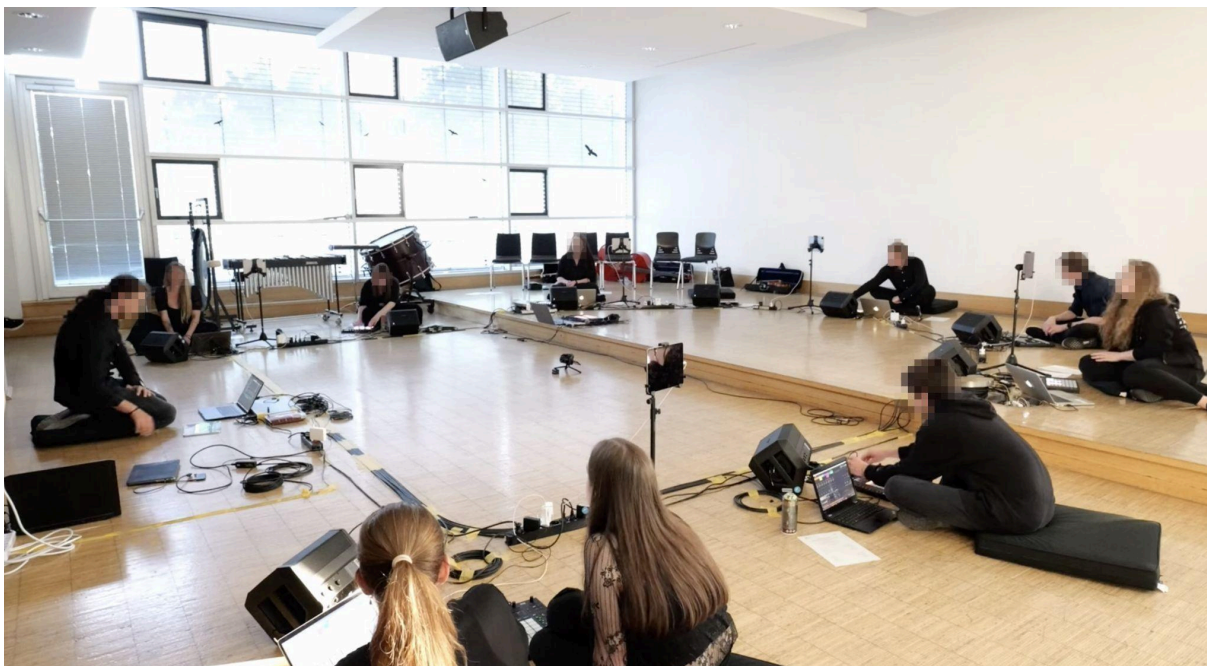

Figure 2. The Musiksaal at the University of Siegen, serving as the primary classroom and rehearsal space for PULSE. (Photo: Wilde, CC BY 4.0 DEED).

In this space, technology facilitates active listening, improvisation, and real-time co-creation. Students engage in responsive musical interactions, attuning to one another's sound, adapting to emergent collective rhythms, and collaboratively negotiating musical structures. The absence of rigid seating arrangements and hierarchical teacher-student divisions allows for a fluid, adaptable, and immersive learning space, where engagement unfolds through movement, conversation, and the shared experience.

The classroom holds the potential to function as a resonant space (*Resonanzraum*) (Rosa and Endres 2016: 34), in which students actively participate in shaping their own learning. Within this space, creative expression can foster transformation (*Anverwandlung*, p. 16) and stimulate critical reflection on students' relationships with technology, space, and learning. At the same time, it cultivates dispositional resonance (*dispositionale Resonanz*, p. 124) through the mutual trust essential to collaborative project creation. By dismantling the spatial and

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[8] All 13 multimedia compositions created by students as part of this study are available on YouTube and can be accessed via the PULSE Laptop Ensemble channel: https://www.youtube.com/@PULSELaptopEnsemble

pedagogical constraints of traditional classrooms, PULSE corresponds with Mütterlein and Fuchs' (2019) concept of digital spatial fluidity, illustrating how postdigital learning spaces can be designed to support resonance as a lived and 'embodied experiences' (see Otrel-Cass 2023).

PULSE takes place in three distinct classroom formats: (1) the Musiksaal, (2) the SoundLab, and (3) the Digital Music Production (DiMuPro) Lab (Figures 3a-3c). The Musiksaal (Figure 3a) is a recital hall with a medium-large stage and flexible seating used by PULSE and other university ensembles for rehearsals and concerts. The SoundLab (Figure 3b) is a modular space that can accommodate lecture-style teaching formats, traditional classroom setups with chairs and desks, and small-scale rehearsals with flexible seating arrangements. The DiMuPro Lab (Figure 3c) is a medium-sized space equipped with three iMac computers, MIDI controllers, MIDI keyboards, audio interfaces, and microphones. The weekly classes are one and a half hours long and take place in the Musiksaal. Every third class session is held in the SoundLab, providing a space for teaching theoretical concepts, facilitating peer presentations of ongoing projects, and delivering in-depth lessons on specific digital audio software. The DiMuPro Lab primarily serves as a space for individual lessons, small-group projects, and independent student work. The spatial arrangement of PULSE in the Musiksaal diverges from traditional classroom structures, replacing fixed seating with a flexible, semi-circular configuration of laptops, speakers, controllers, and floor mat seating (Figure 3a).

Figure 3a. The University of Siegen Musiksaal, the main classroom and rehearsal space. (Photo: Wilde, CC BY 4.0 DEED).

Figure 3b. The University of Siegen SoundLab, a space dedicated to teaching theoretical concepts of digital music composition. (Photo: Wilde, CC BY 4.0 DEED).

Figure 3c. The University of Siegen Digital Music Production (DiMuPro) Lab, a workspace for independent student work. (Photo: Wilde, CC BY 4.0 DEED).

The ensemble consists of ten meta-instruments (see Trueman et al. 2007; Wang et al. 2008), each incorporating a laptop and an iPad connected to a speaker-array station via a Power over

Ethernet (PoE) switch. These are integrated into a Dante network using Audio over Ethernet (AoE) for real-time digital audio distribution.[9]

Data: Student Surveys, Instructor Journals and Audio-Visual Recordings

To investigate PULSE as a potential postdigital resonant classroom, we adopted a qualitative methodology that captures the subjective, spatial, and creative dimensions of the learning experience. The empirical material for this study was drawn from the second-semester cohort of PULSE, composed of twelve undergraduate pre-service teachers (ten music students and two media studies students). The empirical material for this study includes three types of qualitative data.

First, student surveys were collected at the end of the course and served as primary data. These surveys included open-ended questions designed to elicit reflections on spatial experience, collaboration, and the use of technology within the PULSE environment.

Second, we drew on instructor journals, which were maintained throughout the semester as reflective autoethnographic accounts. These journals documented spatial, pedagogical, and technical aspects as experienced by the instructors in the process of designing and facilitating the course. The primary instructor and the co-instructor contributed approximately 13 entries, amounting to roughly 15 pages in total. These practitioner insights provided a second layer of primary data that contextualized and deepened the interpretation of student perspectives.

Third, audio and video recordings of the course were used as supplementary data to support triangulation. These recordings comprised approximately four hours of material, capturing six rehearsal sessions and a final public performance. Beyond documenting spatial arrangements and embodied interactions, the recordings also served as artistic artefacts—final creative outputs that contributed directly to the study. In line with principles of arts-based research (Cahnmann-Taylor and Siegesmund 2018), these performances offered a multimodal, experiential dimension to the data, illuminating how resonance was enacted through sound, movement, and collective artistic expression. As such, the recordings provided a valuable lens into the affective and performative dimensions of the PULSE classroom.

Together, these sources reflect a postdigital research ethos grounded in methodological multiplicity. By integrating diverse forms of empirical material—student reflections, practitioner narratives, audio-visual documentation, and artistic work—this approach reflects *method-emancipation* (Jandrić and Knox 2022): the liberation of research practices from traditional hierarchies and rigid frameworks in favor of more fluid, situated, and creative modes of inquiry.

Student and teacher reflection, audio-visual, and artistic data were coded using Braun and Clarke (2006; 2022) six-phase thematic analysis. We adopted an inductive approach, developing themes through an iterative process. In the later stages of analysis, we drew on theory to interpret the findings. This framework allowed for the integration of theoretical concepts once themes were established.

Empirical Findings: Resonant Space in PULSE

This section presents key findings from the analysis of student survey responses, instructor autoethnographic accounts, and audio-visual recordings from rehearsals and final student

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[9] See Appendix *'Select Visual Data – PULSE Infrastructure and Technology'* for full technical details, including photographic documentation of the ensemble's spatial configuration, networked setup, audio routing hardware, and digital interfaces.

projects. Drawing on reflexive thematic analysis, we identified six recurring themes that contributed to the formation of a resonant learning space in PULSE: (1) spatial comfort, (2) collaboration, (3) spatial constraints/affordances, (4) technology-mediated agency, (5) iterative learning, and (6) future classroom implications. Each theme is discussed below, supported by student quotes, instructor observations, and analysis of the audio-visual data.

Spatial Comfort

A key theme in student feedback was the impact of spatial arrangement on comfort and engagement. The semi-circular setup fostered participation and a strong group dynamic. One student shared, *'Setting up a semi-circle gave me space and comfort to get involved with the new technology. Everyone had a good view of the laptop orchestra leader, so that all instructions could be implemented well.'* Another noted the layout *'strengthened the community and also had a positive effect on the creative process.'* These reflections point to what Rosa (2019: 34) calls a resonance space (*Resonanzraum*), defined by mutual presence and affective attunement. Another student remarked, *'I also liked sitting on the floor because you have more contact with the other course members.'* The absence of desks encouraged spontaneous collaboration, as observed in video recordings showing relaxed, shifting postures and embodied micro-gestures—smiling, mirroring, glancing—that signal receptivity. Rosa and Endres (2016) describe this openness as both corporeal and cognitive: the capacity to be moved and to relate.

Video footage also shows students actively reconfiguring their positions—adjusting laptops, rotating toward peers or instructors—illustrating how spatiality and technological mediation became entangled in moments of postdigital resonance (Wilde et al. 2024). These dynamic interactions fostered what we identify as *resonant learning*: a socially and spatially attuned, technologically mediated experience (White and Wilde 2024). Comfort in PULSE was not a passive condition but a co-created, relational ecology. The openness of the environment fostered student receptivity and engagement, activating a 'triangle of resonance,' of connection in which the classroom emerged as a shared space with the potential to support transformative experiences (see Figure 1).

Collaboration

The PULSE classroom actively shaped collaboration, leadership, and peer support. Students emphasized how spatial flexibility enabled spontaneous, real-time interaction. One student noted, *'When trying out new possibilities, open questions could be answered quickly by the people sitting next to me. Everyone helped everyone and I really enjoyed that.'* This illustrates dispositional resonance—a mutual openness to being affected and to responding, as described by Rosa and Endres (2016: 124). The space became a 'field of meaningful opportunities and challenges' (Rosa 2019: 243), dynamically shaped through social interaction. This dynamic is visible in video recordings: students troubleshoot software, share headphones, and co-navigate sound design. These peer-led moments reflect Rosa's (2019) idea of meaningful world relations, where actions are recognized and absorbed into shared practice. Students did not just share space—they co-produced it.

The setup also allowed for autonomy. A student reflected, *'The spatial arrangement did impact me, as I didn't communicate with other participants about musical choices. It made doing one's own thing possible without losing group context.'* Video and audio data support this dual dynamic: students shifted fluidly between individual and collaborative work, maintaining coherence across diverse activities. As instructors, we observed how this fluidity fostered emergent leadership. Students often took initiative—demonstrating tools, guiding peers—without being prompted. Video evidence from rehearsals and final preparations

captures this redistribution of authority and self-efficacy experiences (Rosa and Endres 2016: 50). Instances of informal peer-support evolved into complex, distributed participation. Students rotated between roles—student, composer, technician, performer, and teacher—reflecting Rosa's (2019: 241) idea of transformation *(Anverwandlung)*, where learners, tools, and environments co-evolve. The collaborative space of PULSE operated as a dynamic learning ecology where shared creativity and relational learning enabled students to extend their capabilities through peer scaffolding, consistent with Vygotsky's (1978) Zone of Proximal Development.

Spatial Constraints and Affordances

While PULSE's spatial design fostered creativity and resonance, students also noted limitations—particularly around sound levels and maintaining acoustic boundaries. One student observed, *'One limitation was the volume, so that the effects were not clearly audible with new content. However, the new content could still be practiced and tried out individually at home.'* This comment highlights a core tension in the PULSE setup: the same openness that enabled dynamic interaction also produced sonic interference that complicated individual focus. These moments reveal what Rosa (2019: 246) refers to as the *material axis of resonance* where environmental conditions, such as spatial acoustics, can either enable or hinder relational engagement. While the openness of the space fostered social cohesion, at times it also contributed to sensory overload. Analysis of rehearsal footage and student project sessions revealed instances where excessive volume and overlapping sound layers inhibited the shared auditory environment. These moments reflect what Rosa and Endres (2016) describe as *dissonance*: a disruption of resonance when material conditions overwhelm the capacity to connect or respond meaningfully.

Another student reflected, *'There have been difficulties and challenges when trying to experiment without disturbing the group.'* This highlights a paradox of co-creative spaces: learning across modalities requires balancing collaborative engagement with individual agency. Video documentation revealed that students adapted to this dynamic by repositioning themselves, lowering volumes, or using headphones—navigating spatial and technological layers with responsiveness. Despite these constraints, they also identified and embraced creative possibilities. One student proposed, *'I had the idea of distributing the speakers in the room so that the audience sits inside and the speakers are distributed around them.'* This concept was realized in a final project, transforming a potential spatial limitation into an immersive composition. As instructors we also experienced similar challenges, with volume disparities occasionally affecting cohesion. To address this, we introduced a custom-built mixer for real-time control of output levels (see Appendix, Figure 5b). The mixer acted as a pedagogical mediator, enabling equitable participation. These strategies reflect the adaptive nature of resonant pedagogy, which, as Rosa and Endres (2016) argue, emerges in the tension between openness and control. Our aim was to maintain conditions in which affective and relational learning could continue to thrive.

Technology-Mediated Agency

Digital tools played a central role in shaping students' agency and creativity within the spatial-pedagogical design of PULSE. Devices like iPads, laptops, Push controllers, and associated software acted as co-agents, inviting experimentation and expanding artistic visions. One student reflected, *'The many different possibilities we discussed in the course gave me lots of different ideas, some of which I hope to use in future projects.'* This generative dynamic was evident in video recordings, where students confidently navigated new interfaces—shifting between hardware and software—with these tools actively shaping

their expressive choices. Another student noted, *'Through the iPads and their apps or the laptops or even the Push devices, you actually had unlimited possibilities to try out new things.'* This is illustrated in rehearsal footage, where students navigate between multiple sound design methods, build complex sonic layers, and iterate on original ideas through digital mediation. These creative interactions contributed to a broader process of transformation *(Anverwandlung)*, in which students exercised agency through their engagement with technology, allowing their artistic identities to evolve in response to new expressive possibilities.

Still, this open environment brought challenges. One student shared, *'During the course, my imagination was somewhat limited by the volume of other students. However, there was the possibility to use headphones to create my own sequence. This helped me a lot to focus on my own project.'* This illustrates a key aspect of technology-mediated agency: students used technological tools—such as headphones, digital audio workstations (DAWs), and spatial audio routing—not only for production, but as strategies for regulating attention, negotiating shared space, and asserting creative autonomy. Video recordings of the sessions show students shifting between collective engagement and individual work, often through technological interventions like putting on headphones, adjusting volume levels, or isolating tracks. These micro-adjustments show how technology afforded flexible modes of participation, enabling learners to calibrate their engagement. We introduced strategies to foster what we came to call *modal learning fluidity*—the ability to shift between collaborative and individual states of learning. This included spatial reconfigurations and use of three classroom environments—Musiksaal, SoundLab, and DiMuPro Lab (Figures 3a–3c)—allowing students to personalize their workflows. From an instructional perspective, we observed how technology mediated not only sound but social interaction. Students often gathered around devices, shared ideas, and offered spontaneous tech support. These exchanges reflect a networked pedagogy of co-creativity, where agency is distributed, relational, and shaped through dynamic learner–technology–space interactions.

Iterative Learning

Findings from PULSE highlight iterative learning—a dynamic, non-linear process where students continuously revisited and reimagined their work. One student remarked, *'I find it exciting to see that you are actually never finished with this seminar. I could visit it a third time and would always learn new things.'* This reflects a core aspect of resonant education: learning as an ongoing transformation across social, material, and postdigital dimensions (Wilde et al. 2024; Rosa and Endres 2016). This openness was evident in video documentation of rehearsals, as students progressively developed and refined their final composition projects across sessions. Some projects evolved subtly; others were transformed entirely through repeated experimentation. Students treated each version not as an endpoint, but as a step in an unfolding creative process.

Our observations confirm that students frequently built on earlier material, integrated peer feedback, and applied new insights in later sessions. These cycles of revision—visible in final performances and rehearsal footage—revealed learning as an evolving dialogue with peers, tools, and space. This aligns with resonant pedagogy, which frames development as mutual and responsive rather than fixed or linear. PULSE positioned knowledge as provisional and malleable. Students understood their projects as nodes within a larger learning ecosystem, constantly open to reinterpretation. This reflects Rosa's (2019) view of resonance as arising through openness to encounter and transformation. Iterative learning here is not just a strategy but a way of being—a recursive, relational practice of becoming-with peers, technologies, and environments.

Future Classroom Implications

Student reflections extend beyond the immediate context of the PULSE course, offering critical insights into how such a model might inform broader educational classroom design. Their responses revealed appreciation for the experience and a sense of its pedagogical potential. One student noted, '*It combines several elements (creativity, technology, music, mindfulness towards others, etc.) and offers many opportunities for teachers and students.*' This perspective suggests that students began to see their learning as something with relational and cultural continuity—linking them to wider creative and educational lifeworlds.

Students' visioning of future classrooms rooted in PULSE principles illustrates the ripple effect of resonance—experiences that are felt deeply tend to be projected outward, generating a sense of purpose that moves beyond the *self* (Rosa 2019). One of the students suggested '*organizing similar projects with high schools or offering a working group in the school that deals with technological possibilities in music production.*' In proposing adaptations of PULSE for different contexts, students were engaging in postdigital design thinking (see Macgilchrist et al. 2024), imagining how hybrid, technology-mediated learning can support inclusivity, engagement, and creative agency across diverse settings.

However, students also expressed concerns about the scalability and accessibility of the PULSE model. As observed by a student, '*I assume that my future school will not have the same equipment as in the PULSE course. If I were to deal with this topic at school, I would have to present a very slimmed-down form.*' This pragmatic acknowledgment draws attention to an important ethical and structural dimension of postdigital pedagogy: while digital technologies can afford resonance, they also risk reproducing inequities if access is uneven or poorly supported (Jandrić and Knox 2022).

We interpret the students' remarks as evidence of a transformation (*Anverwandlung*). They were reflecting on what happened in PULSE and how it might shape their own pedagogical and artistic futures. This reflexive and critical stance signals that students were potential co-designers of future learning environments—a fundamental goal of postdigital education (Brown et al. 2024).

Discussion: PULSE as a Postdigital Resonant Space

This study positions PULSE as a model of a postdigital resonant educational space—an environment where digital technologies are structurally embedded within a resonant learning ecology (cf. Knox 2019; Jandrić and Knox 2022; White and Wilde 2024). Grounded in the empirical findings outlined above, this section synthesizes the key insights into how spatiality, technological mediation, and student agency intertwine to produce meaningful learning experiences. Rather than offering a singular solution, PULSE serves as a case of pedagogical experimentation, challenging dominant narratives of educational technology while contributing to broader discourses on hybrid learning, equity, and creativity in postdigital education (Carvalho et al. 2024; Lindberg and Johansson 2023).

PULSE versus Traditional Classrooms

Traditional classrooms, often characterized by rigid rows and teacher-centric layouts, prioritize control and uniformity, reflecting what Rosa (2019) critiques as the alienation of modern education—spaces where data-driven outcomes are prioritized over connection (see also Barrett et al. 2015). PULSE, by contrast, embodies a hybrid spatiality (Höhl 2024) that seeks to dissolve such boundaries, reflecting Lamb et al.'s (2022: 9) conception of postdigital learning spaces as entanglements of 'social, spatial, and material' dimensions. This hybridity

echoes Wang et al.'s (2008: 30) seminal work on the Stanford Laptop Orchestra (SLOrk), which reimagined the classroom as a laboratory for collective creativity.

Unlike traditional educational settings, where technology might serve as a passive aid (e.g., projectors, speakers), PULSE integrates technology as an active participant, reflecting what Otrel-Cass (2023: 2) refers to as 'embodied entanglements of people with other things (e.g., other humans and non-humans, technical and nontechnical objects).' This *'production of space'* (see Lefebvre 2013) holds the potential to counter alienation in learning by enabling resonant collaboration that traverses both material infrastructures and immaterial dimensions. It affirms Rosa and Endres's (2016) proposition that resonance thrives when subjects and environments mutually transform, and it further reflects what Fawns (2019: 713) describes as 'entangled pedagogies.' PULSE, as a space of postdigital entanglement, offers a site to 'untangle the hidden power asymmetries in the relationship between education and technology' (Rahm 2023: 63) by grounding technology in lived, relational practice.

Countering Commercial Tech Visions

Postdigital science and education critique commercially driven models of teaching and learning that impose pre-packaged, profit-oriented solutions, often limiting student agency (Hrastinski and Jandrić 2023; Aitken and Jones 2023). PULSE resists technological determinism by positioning students as co-creators, echoing Bissell et al.'s (2025) emphasis on 'postdigital learning journeys' that prioritize exploration over prescription. This was reflected in one of the student's comments, saying *'you actually had unlimited possibilities to try out and try new things',* underscores how PULSE's use of open-ended experimental tools supported students' sense of agency, a key element of the laptop ensemble practice (Trueman 2007; Knotts and Collins 2014). Unlike commercially driven educational platforms that standardize learning outputs (Swist and Gulson 2023), student projects in this study demonstrate individualized creativity, informed by students' cultural backgrounds and lived experiences.

This approach challenges the 'solutionism' critiqued by Macgilchrist et al. (2024), where technology dictates pedagogy. Instead, PULSE embodies Ben-Tal and Salazar's (2014) model of collaborative learning with music technology, where students actively shape their environments. By foregrounding resonance in the classroom, PULSE offers an alternative to the 'everyday realities' of teachers and learners subsumed by corporate agendas (Lindberg and Johansson 2023), embodying a postdigital future classroom that prioritizes relationality, co-agency, and meaningful engagement over utilitarian and market-driven models of education (see Lamb and Carvalho 2024).

Implications for Future Classroom Design

The PULSE classroom can be understood as a 'third space' (Johnston et al. 2021)—neither entirely physical nor purely virtual, but a fluid, hybrid environment where digital and material elements converge to shape the learning experience (see Billings et al. 2022). This flexibility also shapes pedagogical practice. Booth (2010) argues that laptop orchestras promote inclusivity—a principle that PULSE integrates into teacher education by preparing future educators from diverse backgrounds and with varying skill levels. This reflects Carvalho et al.'s (2024: 1344) vision of 'positive learning spaces' that support equitable and inclusive education. Moreover, PULSE's public performances—archived on YouTube—extend its spatiality beyond the physical room, engaging with De Souza e Silva et al.'s (2025) theory of *hybrid space*, where networked urbanism connects classrooms to broader social and digital contexts. This conceptual framing is further supported by Carvalho et al. (2016), who explore spatial entanglements in postdigital learning environments, and

Peters and Majid (2022), who examine how digital platforms mediate spatial extensions beyond institutional boundaries.

Limitations and Scalability

Despite its promise, PULSE faces practical limitations that temper its scalability, a concern central to postdigital equity (Lamb and Carvalho 2024). Technical access challenges—such as a student that noted that *'my future school will not have the same equipment'*—highlight resource disparities, a critique echoed by Macgilchrist et al. (2024) regarding uneven educational futures. These constraints reflect Forsler et al.'s (2024) attention to 'geographical locations' in educational futures, where PULSE's model may falter in under-resourced settings. Furthermore, technical challenges, such as system crashes, debugging issues, and the need for software updates, occasionally disrupted the sense of resonance, underscoring Fawns' (2019) point that postdigital integration is inherently imperfect. Yet, scalability remains possible through adaptation. As one of the students suggested, a 'slimmed-down form' using accessible tools like free web-based DAWs, mirrors Tsabary's (2014) transformational education model, which leverages minimal tech for maximum impact. Future iterations could address these gaps by integrating more open-source software and hardware (Bozkurt 2024) to ensure that the postdigital classroom remains sustainable and equitable (Carvalho et al. 2024).

Methodological Limitations

While this study offers valuable insights into the design and implementation of postdigital resonant learning spaces through the case of PULSE, several methodological limitations must be acknowledged. First, the small sample size (n = 12 for the second cohort) and the specific context—pre-service teachers enrolled in a specialized course—limit the generalizability of the findings. Broader applicability would require more diverse participant groups across disciplines and institutional settings. Second, the study relied primarily on qualitative, self-reported data, including student surveys, instructor autoethnographic reflections, and audio-visual analysis. Although consistent with the exploratory and reflexive orientation of postdigital education research (Jandrić and Knox 2022; Jandrić et al. 2023a; 2023b), such methods carry inherent biases and subjectivities. Third, the integration of arts-based methods, particularly audio-visual artefacts and performances, enriched the understanding of resonance but posed challenges for replicability. These highly contextual and interpretive forms complicate cross-case comparison, underscoring the need for systematic, comparative studies across varied postdigital learning environments. Finally, the study was limited to a single semester, providing only a temporal snapshot of inherently evolving educational practices. Future work should adopt multi-perspectival, longitudinal, and cross-contextual designs to more fully capture the transformative potential and structural complexities of postdigital resonant learning environments.

Synthesis and Contribution

PULSE aims to contribute to future postdigital classroom design (Forsler et al. 2024) by materializing a space where technology enables resonant pedagogy (Rosa and Endres 2016). The PULSE classroom, as a 'hybrid learning' environment (Lamb et al. 2022: 6)—shaped by networked, material, and social entanglements—can 'inform the future design of learning spaces' (Leijon et al. 2024: 1460). By resisting the 'marketisation of higher education' (Aitken and Jones 2023: 3) and prioritizing student 'postdigital learning journeys' (Bissell et al. 2025: 3), PULSE holds the potential to shape individual student learning trajectories and

identities. While structural limitations such as unequal access to technology remain a challenge, PULSE's adaptability, open-ended design, and relational grounding position it as a scalable model for 'designing more equitable (postdigital) futures' (see e.g. Macgilchrist et al. 2024: 10). Grounded in Rosa's (2019) concept of resonance, PULSE serves as a compelling classroom model that foregrounds *postdigital resonance* (Wilde et al. 2024) and aims to cultivate *resonant learning* experiences (White and Wilde 2024).

Conclusion

This study examined the Postdigital Laptop Ensemble at the University of Siegen (PULSE) as a postdigital resonant educational space that bridges technology and pedagogy to foster transformative learning. Our aim is to highlight the potential of resonant pedagogy to cultivate affective, relational, and co-creative engagement within postdigital learning environments. Through analysis of qualitative data—including a student survey, autoethnographic reflections, and audio-visual recordings—we explored how PULSE fosters a dynamic learning environment in which resonance, as conceptualized by Rosa and Endres (2016), counteracts the alienation often associated with digitalization in education (see e.g. Pangrazio 2024). By utilizing laptops and other portable digital devices as musical instruments within a hybrid classroom, PULSE reconfigures spatial dynamics to support collaboration, creativity, and inclusivity. This conclusion synthesizes our key findings, articulates our contributions to the discourse on postdigital future classrooms, and proposes avenues for future research.

Our findings suggest that PULSE operates as a postdigital resonant educational space where technology is an embedded, co-constitutive element of the learning environment, supporting Knox's (2019) view of the postdigital as an entangled condition. The flexible spatial arrangement and digital interfaces cultivate a *Resonanzraum*—a space of reciprocal interaction (Rosa and Endres 2016)—evidenced by participants' accounts of mutual support and co-creativity. This corresponds to Wang et al.'s (2008) vision of laptop orchestras as hubs of collective creativity, accommodating diverse skill levels and fostering co-construction of knowledge. In doing so, PULSE transcends rigid, teacher-centric models of traditional classrooms, offering a practical example of the hybrid, interconnected learning environments described by Forsler et al. (2024).

Our contributions to the concept of the future postdigital classroom are twofold. First, we address classroom spatiality through resonance, conceptualizing the postdigital resonant learning space as a sociomaterial assemblage shaped by the interplay of human and non-human actors (Otrel-Cass 2023; Goodyear et al. 2004). Second, PULSE aims to advance equitable and sustainable learning futures by empowering student-led innovative projects and extending resonance beyond the classroom via public performances. These findings position PULSE as a testing ground for reimagining classroom design in a postdigital era, offering an alternative to commercially driven, standardized learning models.

While this study demonstrates the potential of PULSE to foster resonant learning (White and Wilde 2024), its findings also highlight challenges that warrant further investigation. The scalability of such technology-mediated learning spaces remains an open question, particularly in under-resourced educational settings (see Macgilchrist et al. 2024). Future research should explore how adaptive, hybrid learning environments like PULSE can be implemented in K-12 contexts, teacher education programs, and non-formal learning settings. Comparative analyses with other technologically mediated spaces—such as maker labs, virtual reality classrooms, or AI-driven learning environments—could provide deeper insights into the conditions that enable or hinder resonance in postdigital pedagogy.

Additionally, longitudinal studies could assess the lasting pedagogical impact of postdigital ensembles on teaching practices and student engagement in hybrid learning spaces (Trede et al. 2019; Lamb et al. 2025).

As postdigital education continues to evolve, it is imperative that future research critically examines how spatial, technological, and pedagogical configurations interact to shape learning experiences. By advancing scholarship on resonance, space, and technology, this research aims to contribute to ongoing efforts to ensure that the future postdigital classroom is innovative, inclusive, and attuned to the needs of learners. Expanding this discourse will help educators, policymakers, and researchers design learning environments that embrace the affordances of digital technologies while sustaining meaningful, relational, and transformative educational experiences.

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Declarations

Data Availability
Raw data from student surveys and instructor autoethnographic journals are not publicly available in order to protect individual and institutional privacy. Audio and video documentation of classroom sessions and rehearsals are likewise not publicly accessible. However, final student artistic works are publicly available via the PULSE Laptop Ensemble YouTube channel: https://www.youtube.com/@PULSELaptopEnsemble

Conflict of Interest
The authors declare no competing interests.

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Appendix: Select Visual Data - PULSE Infrastructure and Technology

The PULSE ensemble uses ten meta-instruments (see Trueman et al. 2007) equipped with digital audio workstations (DAWs), including Ableton Live 11 Suite (upgraded to Live 12 Suite in the second semester),[10] Logic Pro,[11] and BandLab.[12] Additional software includes visual and text-based programming environments such as Max/MSP/Jitter,[13] Pure Data,[14] SuperCollider,[15] and Sonic Pi.[16] The iPads run iOS applications including Ableton Note, Logic Pro for iPad, MusiKraken,[17] and TouchOSC.[18] Each performer station utilizes floor mats for seating, which allows for a flexible and dynamic spatial arrangement of performers (Figure 4a and 4b). The networked stations extend the space into a digital environment, enhancing the interconnectedness of digital and physical interactions within the ensemble. The semi-circle configuration facilitates multidirectional listening and collaboration, an essential aspect of live performance. A critical component of PULSE is its audio-over-ethernet (AoE) network, which enables signal transmission between multiple computers and digital audio devices. The managed gigabit switch serves as the backbone of PULSE's audio network, allowing students to engage with networked audio concepts and digital signal routing (Figure 4c). This infrastructure bridges music technology with computer networking principles, providing an experiential learning opportunity beyond conventional music instruction. The integration of the Dante network further strengthens PULSE's digital infrastructure, enabling low-latency, high-fidelity sound transmission. Using the Dante virtual soundcard and software, students experiment with, route, and manage digital audio signals, with the goal of enhancing their understanding of professional sound networking and expanding their creative possibilities with multichannel audio (Figure 4d). PULSE incorporates cutting-edge digital audio interfaces to facilitate modular and flexible signal routing.
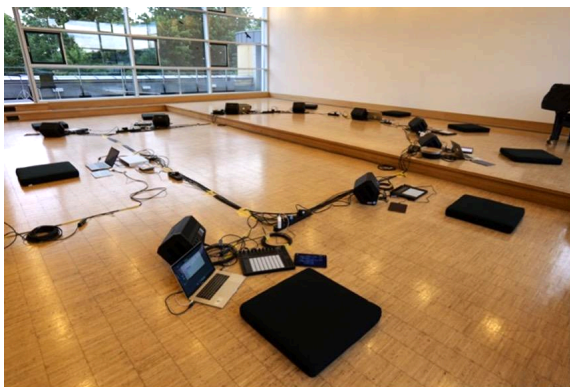

Figure 4a. PULSE, view from right. (Photo: Wilde, CC BY 4.0 DEED).

Figure 4b. PULSE view from center stage. (Photo: Wilde, CC BY 4.0 DEED).

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[10] https://www.ableton.com/en/shop/live/

[11] https://www.apple.com/logic-pro/

[12] https://www.bandlab.com/

[13] https://cycling74.com/forums/jitter

[14] https://puredata.info/

[15] https://supercollider.github.io/

[16] https://sonic-pi.net/

[17] https://www.musikraken.com/

[18] https://hexler.net/touchosc

Figure 4c. LO audio over ethernet (AoE) network used during LO classes. USW-48-POE 48 port Managed Gigabit L2 L3 Switch - 48x with Gigabit Ethernet Ports with 32 POE+, students learning about computer technology networks. (Photo: Wilde, CC BY 4.0 DEED).
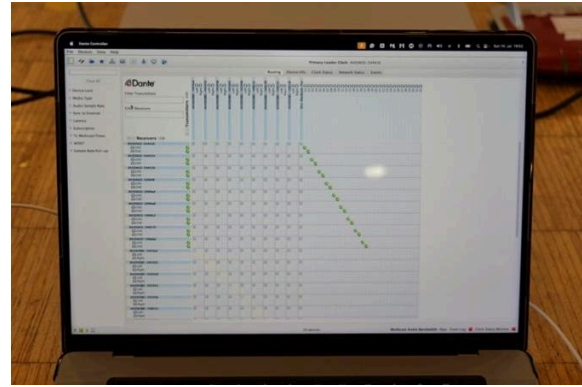

Figure 4d. Audinate Dante Network (professional networking technology). Students learn about signal routing using the network, discovering, and routing signals with Dante Controller, Dante devices, and network switch. (Photo: Wilde, CC BY 4.0 DEED).

Each station is equipped with a USB Type-C I/O Audinate AVIO 2×2 and an AVIO Analog Output 0×2 adapter, enabling integration of analog and digital audio sources (Figure 5a). Various digital controllers and software enhance creative and performative possibilities. The iPads, running TouchOSC, allow students to design customizable graphical user interfaces, transforming tablets into personalized MIDI controllers (Figure 5b). The integration of the Ableton Push 2 controller with the MusiKraken application on iPads further emphasizes the multimodal and embodied nature of digital performance in PULSE (Figure 5c). Through Bluetooth MIDI connectivity, students manipulate digital sound in real-time via hand and body movements, fostering an interactive and immersive learning environment. Additionally, the MusiKraken visual programming app enables students to create custom motion-tracking MIDI controllers on iOS devices using touch input, motion sensors, and camera-based tracking (Figure 5d).

Figure 5a. USB Type-C I/O Audinate AVIO 2×2 and AVIO Analog Output Adapter 0x2 for routing. (Photo: Wilde, CC BY 4.0 DEED).
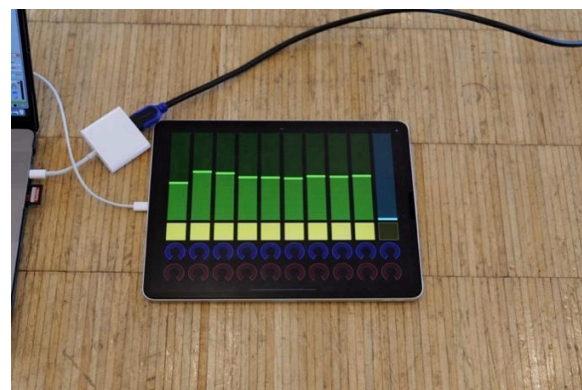

Figure 5b. Main mixer iPad running TouchOSC software. (Photo: Wilde, CC BY 4.0 DEED).
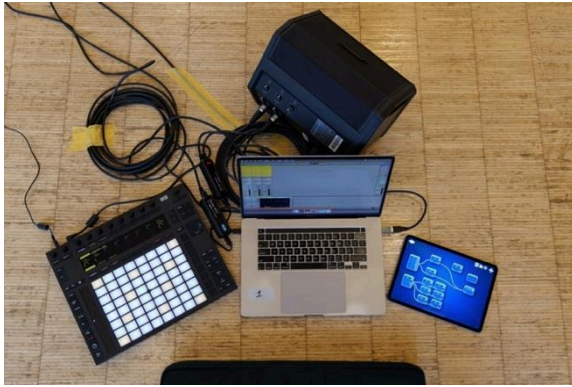
Figure 5c. Performance station running Ableton Live Digital Audio Workstation (DAW) with the Push 2 – digital controller and an iPad as a wireless body tracking MIDI controller setup via Mac Audio Midi Setup - MIDI Bluetooth Device. (Photo: Wilde, CC BY 4.0 DEED).
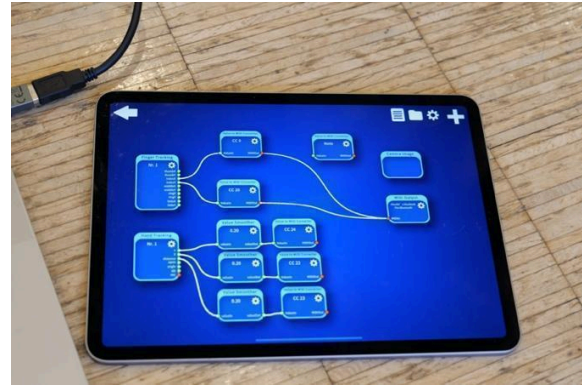

Figure 5d. MusiKraken visual programming app on iOS (or Android devices) used for designing individual/personalized MIDI controllers using touch, motion sensors and camera (tracking hands, face, body or color). (Photo: Wilde, CC BY 4.0 DEED).

These images provide an overview of the spatial arrangement and technological setup of PULSE, and illustrate how the space is organized to support interactive, networked, and collaborative music-making and learning. By integrating audio networks, interactive controllers, and visual programming tools, PULSE aims to cultivate a resonant learning ecology where students co-create knowledge through sound, movement, and digital mediation.