

Teaching Sound Design in a Shared Mixed-Reality Modular Laboratory: A Formative Case Study of OpenSoundLab

Ludwig Zeller

Institute Digital Communication Environments

Basel Academy of Art and Design FHNW

Basel, Switzerland

ludwig.zeller@fhnw.ch

Abstract—This paper presents a formative case study of a five-day sound-design workshop conducted with OpenSoundLab (OSL), a source-available mixed-reality modular sound laboratory. The study responds to a pedagogical tension in modular synthesis: hardware workshops offer tactile and spatial learning but are costly and limited in access, while software environments such as DAWs, Max, Pure Data or VCV Rack reduce patching to screen-based workflows. The workshop took place at HGK Basel from September 16 to 20, 2024 with nine participants who had sound, music, hardware or DAW experience but little prior extended reality (XR) or modular synthesis experience. The analysis draws on lecturer observation, lecturer-recalled participant dialogue, a post-workshop questionnaire completed by eight participants, selected project examples and public Zenodo documentation. Within this bounded case, OSL functioned as pedagogical infrastructure: guided instruction, personal patching, peer visits, mentoring and final presentation all took place inside the same mixed-reality app. The strongest affordances were spatial organization, shared patch visibility, multiplayer presence and performable artifacts, while headset onboarding, nausea, optical limitations, beginner scaffolding and interrupted flow constrained its use. The case suggests that shared mixed-reality modular environments are best understood not as replacements for DAWs or hardware studios, but as complementary studio-workshop formats for XR sound and music practices.

Index Terms—mixed reality, sound design, modular synthesis, spatial audio, music education, OpenSoundLab

I. INTRODUCTION

Music-technology pedagogy differs by instrument and interface. Guitar or singing lessons can begin from a visible body-instrument relation, while DAW teaching often centers on standardized screen-based arrangement, editing and production workflows. Generative modular sound design is different: learners build temporary machines whose signal flow, modulation and listening position become part of the musical situation. Hardware workshops make this tangible, but complete modular systems are costly and limited in number.¹ Software environments such as Max, Pure Data or VCV Rack improve access, yet often return patching to a screen-bound workflow with mouse interaction and small visual workspaces; bodily

performance and tracked spatial listening usually require extra controllers, tracked headphones or loudspeaker infrastructure, which are often too complex or costly for educational settings [1], [2]. This creates a pedagogical question for research on XR sound and music practices: what changes when sound-design concepts are taught inside a shared mixed-reality environment where patches can be seen, heard, moved through and manipulated together?

Recent work has examined XR music education, mixed-reality singing lessons, immersive vocal practice, shared musical metaverse systems, collaborative virtual instruments and web-based immersive audio graphs [3]–[9]. Taken together, this work marks XR sound pedagogy as an active research area rather than a marginal application. Less documented is how a shared mixed-reality modular sound environment can function as a multi-day teaching medium for sound-design fundamentals in an art-school workshop.

This paper examines the OpenSoundLab (OSL) sound-design workshop held at HGK Basel, Academy of Art and Design FHNW, from September 16 to 20, 2024. Nine Bachelor-level elective participants completed the workshop. They generally had experience with sound, music, songwriting, DAWs or popular electronic genres, but little prior experience with XR or modular synthesis. Using Meta Quest 3 headsets, participants first followed guided sound-design instructions within the co-located mixed-reality environment, then developed short musical or artistic projects and presented them on the final day.

Here, mixed reality (MR) refers specifically to camera-based passthrough of the physical studio with virtual sound modules. Co-located MR means that participants share the physical room and aligned virtual coordinates. XR is used as an umbrella term when discussing the broader literature on virtual and mixed reality.

OSL began as a private artistic project driven by a fascination with bringing both the interface and aesthetics of modular sound synthesis into 3D space. It is based on Logan Olson’s open-source SoundStage VR, adapting a room-scale VR music sandbox toward passthrough mixed reality and more professional sound-lab use [10]. During the COVID-19 pandemic, FHNW financed an institutional development phase as a way

¹This budget comparison concerns a sufficiently equipped hardware modular rig per student, estimated at several thousand CHF per station. Nonetheless, providing a class set of headsets also entails a substantial equipment expense.

to make spatial sound-lab experiences available despite limited hardware budgets and home-based access constraints. An early version was documented in prior OSL work, with Hannes Barfuss contributing four modules during that phase [10]. Subsequent research used OSL and PatchWorld as case studies for how modular synthesis’s social ethos, tactile appeal and spatial organization might translate into XR, while a NIME performance contribution treated OSL patches as walkable, entangled environments [11], [12]. The present paper shifts the emphasis from system and practice research to pedagogy. It asks what the September 2024 workshop reveals about teaching sound-design basics through shared spatial modular patching.

The study is not a controlled comparison of learning modalities. It combines lecturer observation, recalled participant dialogue, a post-workshop questionnaire, selected project vignettes and public Zenodo documentation [13]. The paper documents a class-scale workshop, identifies affordances around spatial distribution, shared patch visibility, direct experimentation and multiplayer presence, and reports constraints around onboarding, comfort, scaffolding, tactile feedback and production infrastructure. The contribution is a formative account of how a shared MR modular system behaves as a teaching infrastructure that produces affective and spatial engagement while straining interaction flow and sustained co-production.

II. RELATED WORK

A. XR Music and Sound Pedagogy

XR music education has become a visible research topic, but much of the strongest evidence comes from task-based or lesson-based studies rather than studio-workshop cases. Bruns et al. compare presence and flow in multi-user music-related XR settings through an interactive musical memory task implemented in PatchWorld and a 2D Fortnite environment [5]. Their distinction between presence and flow matters here because a socially present workshop can still create cognitive load and interrupted interaction flow.

Immersive Vocal Practice offers a smaller practitioner-centered evaluation of VR rehearsal with real-time vocal auralization and visual reconstruction of a theater space [9]. Sonic Metaverses similarly examines how embodied theater and vocal training can be translated into responsive XR environments and living archives [14].

B. Shared XR Sound Tools and Musical Metaverse Systems

A useful cultural comparator is PatchWorld, a social XR environment for modular synthesis, music-making and world-building. Prior work describes it as a participatory culture in which virtual modular patching becomes shared practice, while also foregrounding the fragility of platform-dependent creativity in closed ecosystems [11]. Bruns and Rotsch’s LEVIKO-XR study frames PatchWorld for school music education and teacher professional development, while a practitioner-facing PatchXR account documents it as a shared VR workshop environment [15], [16]. This makes PatchWorld relevant for pedagogy, but also marks an important difference: its documented

workshop sociality is primarily avatar-based VR, whereas the OSL workshop studied here used co-located passthrough MR, keeping students visually situated in the same physical studio while sharing spatial modular patches. Turchet’s work on the musical metaverse frames broader opportunities and challenges for multi-user musical XR and Internet of Musical Things environments [17]. Boem and Turchet’s Musical Metaverse Playgrounds demonstrates a browser-based model for shared sonic environments using WebXR, Networked-AFrame and Web Audio [3]. Boem et al.’s study of shared virtual musical instruments adds a design point directly relevant to OSL: collaborative instruments must support performer-instrument interaction and performer-performer interaction at the same time [4].

Related web-audio studies by Buffa, Girard and Hofr [7] and Buffa et al. [8] foreground web audio components, WebXR collaboration, 3D audio interfaces and usability challenges in spatial audio-graph manipulation. Hopkins et al. introduce MR-DAW as a DAW-oriented comparator, using Quest 3 headsets, Unity, Ableton Live, OSC and a Python control layer to support collaborative control of a shared DAW session [18]. Dziwis, von Coler and Porschmann describe Live Coding in the Metaverse as a further pattern in which networked immersive environments support performance practice [19]. Earlier NIME work also addressed modular synthesis directly in XR: Wakefield, Palumbo and Zonta examined the affordances and constraints of modular synthesis in virtual reality [20]. Compared with these works, the OSL case contributes a pedagogical account of how networked mixed-reality sound tools behave when used as a sustained workshop infrastructure.

C. OSL and Spatial Modular Patching

Prior OSL work supplies the system and practice background. In a 2022 system paper, OSL is discussed as an emerging laboratory for sound practice: a way of bringing modular synthesis, spatial listening and experimental studio work into a portable mixed-reality setting [10]. The project responded to a specific tension in digital audio culture: software made sound work flexible and reproducible, but often weakened its spatial and bodily dimensions. Later work places OSL within a broader XR modular culture, where the question is not simply whether analog hardware can be simulated, but whether modular synthesis’s spatial, tactile and social qualities can be reworked in virtual and mixed-reality settings [11]. These qualities are also relevant for the present study, because collaboration in OSL depends on patches becoming shared environments rather than private screen-based workflows.

OSL is positioned as an open-source, MR-first and comparatively streamlined system for professional, academic and artistic use. The Walkable Instrument presents OSL patches as spatially arranged, audience-legible and site-responsive [12].

D. Pedagogical Frame and Gap

The workshop can be effectively understood through four complementary pedagogical frameworks: studio, project-based, maker-oriented, and modular pedagogy. Studio peda-

gogy foregrounds demonstration, making, critique, presentation, and reflective practice [21], [22], while project-based learning emphasizes sustained inquiry, scaffolding, collaboration, and support for learning rather than the assignment of open-ended tasks alone [23]–[25]. Building on this iterative process, constructionism and maker learning frame built artifacts as evidence of learning activity [26], [27]. Finally, modular synthesis pedagogy adds a more specific lens: it treats patching as hands-on, exploratory, technically informed, and collective, with visualization, direct signal manipulation, co-creation, and reflection as central workshop elements [1], [2]. Within this modular framework, Thumlert et al. further frame learning as parametric, material-centered inquiry that can challenge inherited talent regimes in music education, while Lecours and Gagnon-Legault demonstrate how progressive modular studies can separate patch-construction instructions from performance manipulations, treating both as integral to instrumental practice [28], [29]. Collectively, these approaches position the workshop as a space where technical exploration, iterative making, and collaborative critique converge to support learner-centered instruction.

III. OSL AND WORKSHOP DESIGN

The case is a five-day OSL sound-design workshop held at HGK Basel in September 2024. It was taught by the author and completed by nine Bachelor-level elective participants from visual communication, art, industrial design, process design and art teacher education. Participants generally had private or semi-professional experience with sound, music, songwriting, DAWs or popular electronic genres, but little prior XR and modular synthesis experience. Among the eight questionnaire respondents, seven rated their prior VR/MR experience 0 or 1 on the 0–5 scale; prior sound/music experience ranged from 1 to 5, with a median of 4. The workshop therefore had to introduce headset interaction, OSL operation and modular sound-design concepts in the same week.

Full workshop days were scheduled approximately 9:00–16:30, with an hour for lunch and two 30-minute breaks; Monday began in the afternoon and Friday centered on presentations and evaluation. Actual headset use was 5–7 hours on full days, including optional work outside scheduled sessions.

OSL was used as teaching environment, instrument and creative workspace. In the September 2024 workshop build, modules appeared as mixed-reality objects that could be placed in the room, connected with virtual patch cables, scaled, moved and arranged into larger structures. Co-located sessions used networked shared state, so participants could see one another’s modules, observe patch manipulation and work around the same spatial sound-design objects. The workshop build did not include passthrough depth occlusion, so virtual elements were always rendered on top of the camera-based passthrough view of the physical room and participants’ hands.

Modules available in the teaching patches included an oscillator and LFO, a noise source, a filter, two envelopes, a sequencer, two samplers, a looper, mixers and effects, with an oscilloscope and FFT display for signal inspection.

These supported subtractive synthesis, FM and AM, sampling, generative sequencing and binaural placement [30].

Technically, the workshop used OSL’s local multi-user architecture. OSL ran as a Unity-based Meta Quest 3 application, making Mirror, an established Unity game multiplayer framework, a practical choice. The setup reused its conventional host/client networking and object synchronization, with OSL-specific audio synchronization built on this infrastructure. Chris Leisi and Christoph Müller of ArchLevel GmbH contributed the multi-user implementation, completing it just in time for the September 2024 CoCreate workshop studied here. A host headset exposed a shared session over local Wi-Fi using Mirror’s KCP transport over UDP, and other headsets joined it. KCP adds reliable, ordered delivery to UDP through acknowledgments and retransmission, with an emphasis on low latency. The host maintained shared patch state, while clients temporarily controlled module transforms during grabbing. After manual co-location calibration, shared objects were placed in a common patch space. Module transforms, cable connections, parameter states and user head and hand positions were synchronized through this host/client session, while menus remained private. Each headset computed its own audio graph through Unity audio callbacks and native DSP routines, at a configured sample rate of 48 kHz (Fig. 1).

Audio synchronization exchanges noise seeds and sequence positions, internal phases and module events or states, with full state updates on session join, headset resume or manual beat-clock rewind, see [11, p. 8] for more detail. However, occasional synchronization problems can occur, e.g. network jitter in time-critical situations such as pitch modulating an LFO can produce audible discrepancies through accumulated phase offsets. Our interaction-driven audio synchronization was able to compensate such issues in most cases, but not in all edge cases e.g. involving certain complex modulation patches. Audio discrepancies were not evaluated specifically during the workshop.

Patches were saved as XML files containing module settings, spatial arrangements and cable connections. Samplers synchronized sample-file references, so the corresponding audio files had to be available locally on each headset.

The workshop opened with a contextual introduction to OSL and the dematerialization of electronic sound practices through digitization, presented as projected slides. Each participant then received a Meta Quest 3 headset with a BOBOVR halo-style battery strap. Because most participants were new to the Quest 3, headset setup, visual sharpness, strap adjustment, Meta Quest interface states and entry into OSL became substantial first-day work. The group then used a printed floor marker and a two-controller pose-alignment workflow adapted from the Co-Experiencing Virtual Spaces framework for aligning tracking areas in same-space multiuser VR [31]. This created a shared spatial reference so that OSL objects appeared in corresponding positions for all participants.

From Monday afternoon to Wednesday morning, the guided phase moved from basic spatial interaction to increasingly complex generative and binaural sound-design patches. These

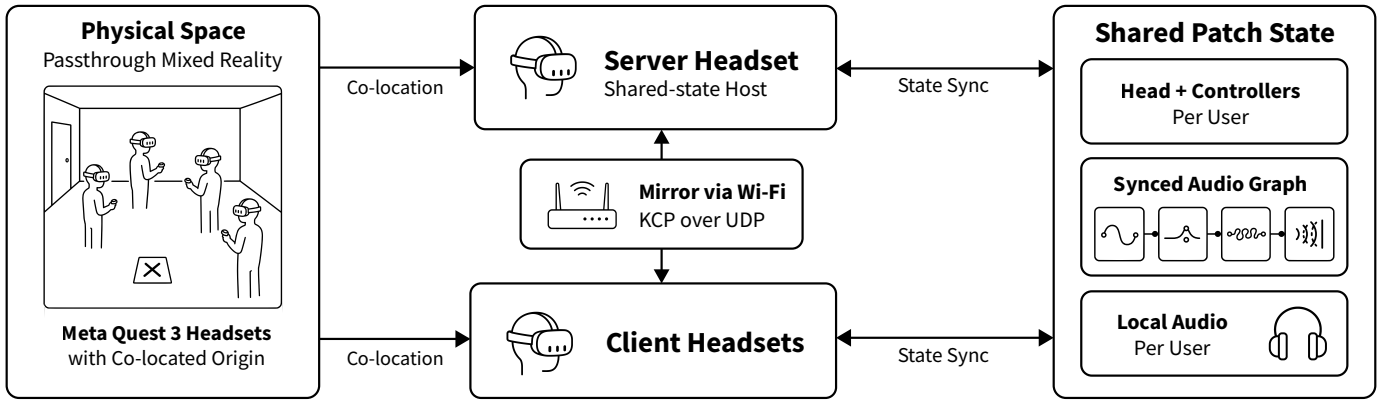


Fig. 1. Technical setup of the September 2024 OSL workshop. A host headset coordinated shared patch state and co-located user poses over local Wi-Fi using Mirror’s KCP transport over UDP. Each headset evaluated a local audio graph, with optional binaural outputs rendered from its user’s listening position.

sessions were adapted from OSL’s prerecorded in-headset video tutorials and bundled patch examples, originally created as a solo-learning sequence for individual headset practice [30]. Demonstration patches could be scaled to room-filling size and rotated and positioned freely, so students could stand around them and perceive signal flow as a spatial arrangement.

On Wednesday afternoon, the workshop shifted to independent project work. The brief asked each participant or group to develop a musical or artistic presentation of up to five minutes and encouraged them to use modular synthesis strengths rather than reproduce familiar DAW or keyboard patterns. Thursday was dedicated to development, mentoring and technical support. Participants could expose an individual headset as a local-network server, allowing peers or the lecturer to join their sessions. These personal sessions avoided a single overloaded class patch and an unmanageable sound mixture, but they also reduced spontaneous peer awareness because headsets limited eye contact, facial expression and quick over-the-shoulder observation. Friday included final presentations, discussion and questionnaire completion.

No crashes were reported during the workshop, while headset adjustment, heat, optical sharpness, co-location precision and Meta Quest onboarding took time away from sound-design instruction. Participant-reported comfort constraints are detailed in the findings.

IV. RESEARCH QUESTIONS AND ANALYTIC LENSES

The workshop was a practice-led teaching intervention that later became the basis for a reflective case study. Because the research questions were refined after the workshop, the paper does not treat them as hypotheses to be tested. Instead, they organize a retrospective reading of the case. The central concern is what pedagogical affordances and constraints became visible when OSL was used to teach sound-design basics in a five-day co-located mixed-reality modular workshop. A second concern follows from the participant projects: how guided instruction was translated into spatial, modular, collaborative or site-specific sound-design work.

The analysis approaches these concerns through three connected lenses. Spatial scaffolding draws attention to how distributed patching supported or complicated conceptual mapping, cognitive load and the need for explicit instruction. Social legibility focuses on multiplayer patching as a situated group practice, including shared visibility, peer awareness, collaboration and the design of co-located sessions. A final lens treats OSL as a complementary studio medium: a hybrid teaching, making and presentation environment that sits alongside DAWs, hardware studios and conventional teaching formats rather than replacing them.

V. METHODS

The study is a reflective formative case study combining descriptive questionnaire results with a retrospective interpretation of lecturer observations and selected project documentation. It follows Yin’s logic of examining a contemporary phenomenon in depth within its real-world context, where the boundaries between the teaching intervention and its technical, project-based, and institutional context are not clearly evident [32]. The case is the September 2024 OSL workshop at HGK Basel; the central object of analysis is how the system structured sound-design teaching, participant experimentation, project development and presentation.

The evidence base combines workshop records and lecturer observation, lecturer-recalled participant dialogue, a post-workshop questionnaire, selected participant experiments and public Zenodo documentation [13]. Eight participants completed single-item ratings and open-text questions on workshop experience, OSL, spatial distribution, collaboration, creativity, fatigue, nausea, novelty and desired features. The questionnaire was not a validated psychometric instrument and is interpreted descriptively as formative participant feedback, not as evidence of learning gains. Each spatial-distribution item and the missing-feature question had seven responses because one entry was blank; the other reported rating items had eight. Missing entries were excluded item by item. Project vignettes are likewise treated as selected artifacts showing how guided instruction translated into participants’ own sound practice.

Questionnaire responses were read alongside lecturer observation, recalled dialogue and project documentation to identify recurring affordances and constraints. The author developed OSL, taught the workshop and conducted the analysis. Agreement among these sources supports the interpretation but does not provide independent verification or remove confirmation bias. Recalled dialogue provides contextual evidence rather than a systematically recorded or coded dataset.

Participants signed consent for research use of questionnaire and documentation material, including images and headset recordings. Research participation and use of images were voluntary and could be declined without consequences for workshop participation. Consent included public archiving and publication of the recordings without further anonymization. The workshop video is publicly archived on Zenodo as *CoCreate.mp4* and provides an audit trail for the workshop context and selected project examples [13].

VI. FINDINGS

The central pattern is not simple enthusiasm, but affective engagement without stable interaction flow: participants often recommended the workshop and reported joy, while flow, instruction-following and future professional use remained more mixed.

A. Mixed Reality as a Creative Medium

Questionnaire responses indicate that participants generally welcomed OSL as a workshop medium. On the 0–5 scale, 6/8 reported 4 or higher for recommending the workshop, and 7/8 did so for OSL itself; both items had a median of 4.5. 6/8 also reported 4 or higher for joy and connection with their creations. By contrast, future use for audio work was more tentative: 4/8 reported 4 or higher, with a median of 3.5. The novelty item also had a median of 3.5, so these positive responses should be read together with the effect of first exposure to headsets, spatial patching and a new workshop format.

B. Spatial Patching and Interrupted Flow

Spatial presentation was distinctive, but the evidence is mixed. Among valid responses, 5/7 reported 4 or higher for spatial presentation supporting learning, and 4/7 did so for spatial distribution making audio techniques more fun; both items had a median of 4.0. Flow was much weaker: only 1/8 reported 4 or higher, with a median of 2.5. Understanding and recreating the lecturer’s instructions was also uneven, with 3/8 reporting 4 or higher. The workshop made sound-design processes spatially engaging while also increasing cognitive and practical demands.

Project evidence shows where spatiality became concrete. In the following sections, P1–P7 denote selected project or experiment examples documented in the Zenodo video *CoCreate.mp4*, not participant identifiers. P1 made modulation visible through a large waveform visualization (Fig. 2); P6 arranged seven tracks into a branching room-scale structure feeding a central mixer; and P7 extended spatial sound beyond

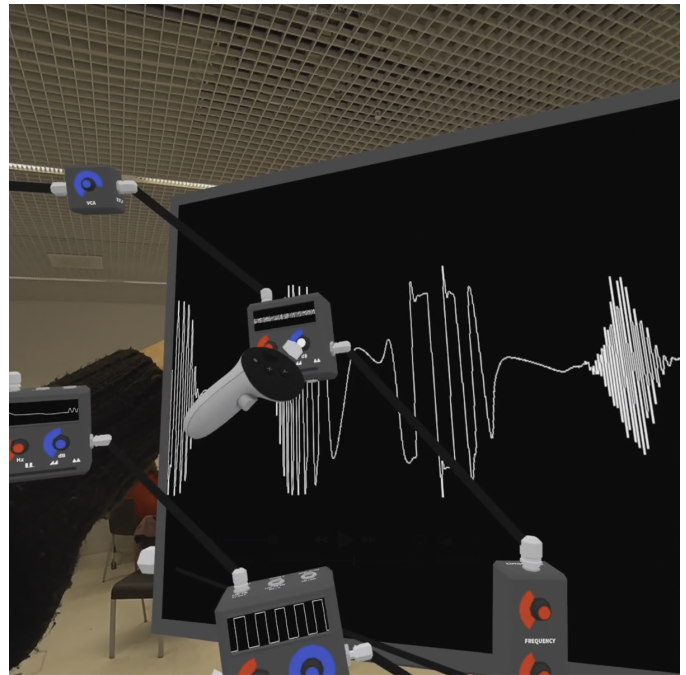


Fig. 2. P1: Large waveform visualization in a midweek synth experiment (CoCreate.mp4 02:07:42:00).

the seminar room through a binaural synthetic jungle beneath campus trees (Fig. 7). These examples suggest that OSL’s spatial value was strongest when layout, listening position or site became part of the work rather than merely a visual container for conventional synthesis.

C. Multiplayer and Uneven Collaboration

Four of eight respondents explicitly mentioned multiplayer presence, joining rooms or working together as valued features in best-feature or additional-comment fields. In the guided phase, co-located mixed reality made the lecturer’s demonstration patches visible as shared spatial objects rather than a flat projection. In the project phase, participants could inhabit a shared patching space, see modules handled by others and join project sessions for mentoring or peer visits.

The workshop therefore showed several layers of multiuser sociality: shared instruction, one-to-one mentoring, quick peer visits and final presentations in a common room-scale patch space. Sustained hands-on co-production was narrower. All but two participants worked individually, with one pair developing the clearest collaborative project. P3, a large patch with arpeggios and drums, is therefore the strongest evidence for peer collaboration in the selected project set (Fig. 3). This distinction matters because social co-presence, peer visibility and collaborative authorship are related but not identical. Uneven uptake may reflect the first-iteration workshop format, the cognitive load of a new tool, local studio habits around individual projects or participant preference rather than a simple lack of collaborative affordance.

Personal sessions helped keep patches technically manageable and prevented different projects from interfering sonically



Fig. 3. P3: Collaborative patch with arpeggios and drums (CoCreate.mp4 02:10:53:56).

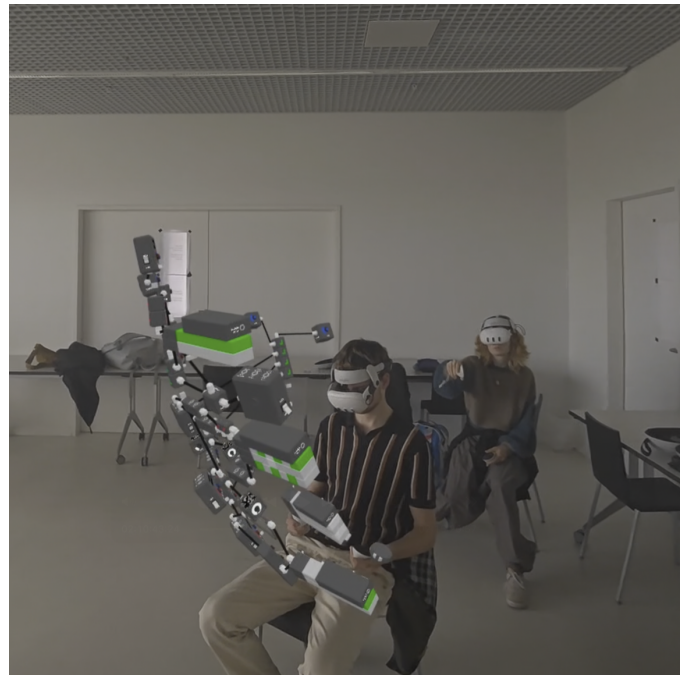


Fig. 4. Personal project bubbles during free experimentation and practice time (CoCreate.mp4 around 02:10:00:00).

with one another (Fig. 4). Their drawback was reduced social awareness. Wearing headsets made eye contact impossible, masked facial expression and left participants partly isolated in their own project bubbles. At the same time, these bubbles were not fully closed. Participants could still visit one another’s sessions, ask for help or encounter ideas from neighboring projects, although these visits remained silent at the system level because user names and join notifications were not implemented in the 2024 OSL build. This personal-bubble situation may also have supported deep focus, since reduced eye contact and fewer classroom cues gave participants more uninterrupted time with their own patches.

D. Project Translations of Guided Instruction

The selected examples show several translations of that instruction. P2 continued ambient-style patching after the participant took the headset into a personal studio. P4 connected the workshop to production-oriented musical practice through a downbeat patch with a microtonal scale, performed by scrubbing through a sequencer (Fig. 5). P5, an ambient drone with bell-like sounds and a vertical visualization, pointed toward installation-like presentation (Fig. 6). P6 made arrangement and signal flow legible as a spatial diagram, while P7 used FM, AM and subtractive synthesis for synthetic animal-like sounds placed outdoors in a binaural scene (Fig. 7).

These vignettes should be read as selected evidence rather than a complete account of all projects and presentations. P1–P7 are included because they are visible in the public Zenodo documentation; P8 and P9 are not analyzed because they are not included in the available video evidence. Their significance is not that participants used OSL in one consistent

way, but that the guided exercises opened several different routes into sound practice. Some participants treated OSL as a laboratory for visualizing modulation and signal flow, others as a personal sketching environment or performance interface, and others as a medium for installation-like, spatial or site-specific binaural presentation. This unevenness is part of the finding: OSL did not produce a single workshop genre, and sustained collaboration appeared clearly in only one selected project, but the system allowed participants to move from shared instruction into divergent musical, spatial and presentational forms.

E. Scaffolding, Comfort and Production

The main constraints shaped what could be taught, how quickly participants could work and how much attention remained for sound-design concepts. 4/8 open responses mentioned instruction pacing, beginner difficulty or a lack of next-step prompts. This fits the combined burden of learning headset use, mixed-reality interaction, OSL’s interface and modular signal flow in only five days.

Comfort and sensory load were recurring constraints. Nausea was not described as extreme, but it remained present, with a median rating of 2.0 on the 0–5 scale. 6/8 fatigue explanations named nausea or VR sickness, and 2/8 mentioned visual issues. These responses match lecturer observation that headset fit, heat, strap adjustment and visual sharpness affected onboarding and continued to shape the experience. It remains unclear how much fatigue would have persisted under an optimal setup during such extended use.

Feature requests centered on editing and recovery, spatial organization and clearer multiplayer recording behavior. 6/7

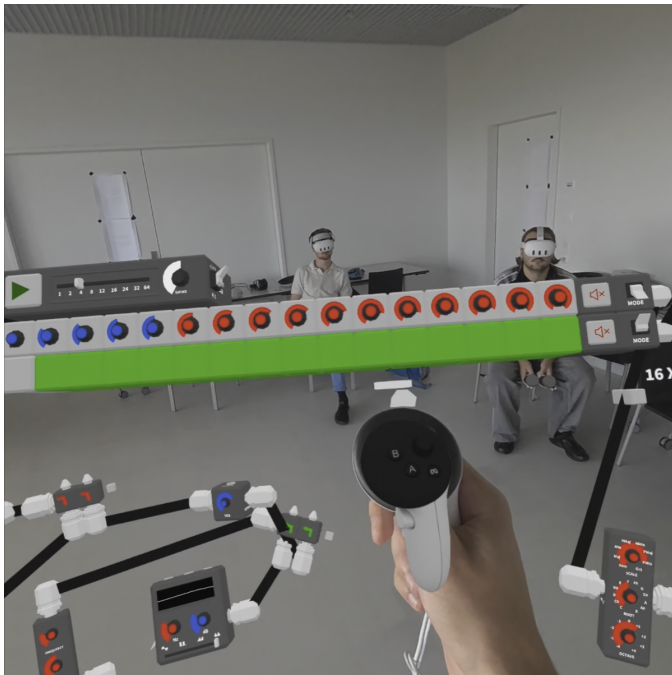


Fig. 5. P4: Sequencer-based downbeat patch performed through microtonal scrubbing (CoCreate.mp4 02:11:30:13).



Fig. 7. P7: Binaural synthetic jungle presented beneath campus trees (CoCreate.mp4 02:14:40:00).



Fig. 6. P5: Ambient drone with bell-like sounds and vertical visualization (CoCreate.mp4 02:12:56:45).

valid missing-feature responses named practical editing, organization or recording features. One valid response explicitly emphasized tactile limits by asking to touch the objects being worked with.

VII. DISCUSSION

A. A Mixed-Reality Studio

In this workshop, OSL functioned as a hybrid studio environment. During guided instruction, it served as a classroom diagram; during project work, it became an instrument and workspace; during final presentations, a performance and exhibition medium. This convergence matters because studio and modular workshop pedagogy depend on making, demonstration, direct patching, critique, peer awareness and public presentation [1], [21], [22]. OSL did not replace those practices, but altered their material conditions by letting the teaching object, creative artifact and presentation space partly overlap. What transferred most clearly was not the tactile materiality of hardware modular synthesis, but the social and spatial organization of studio work: shared visibility, demonstration, peer visits and presentation around a common artifact.

B. Spatial Patching as Artifact-Based Learning

The findings position OSL within constructionist, maker-oriented and modular learning traditions, where building, testing, debugging and sharing artifacts become central to learning [26]–[28]. Participants built patches that embodied filters, modulation, sequencers and spatial audio in visible and audible form. P4 turned sequencer interaction into a performance gesture (Fig. 5), P6 made arrangement and mixing readable as a spatial diagram and P7 used binaural placement and campus context as compositional material (Fig. 7).

For many modular practitioners, the reward of patching lies not only in the resulting sound, but in constructing a

temporary musical machine whose behavior can be traced, modified and performed [11]. OSL extends this logic by making the musical machine spatial and shareable. The patch is not only a signal chain hidden inside a screen or device; it becomes a room-scale arrangement that can be walked around, inspected, discussed and reconfigured. This may help explain why participants experienced spatial patching as engaging even when flow and instruction-understanding results indicate additional cognitive load. It also aligns with embodied and mixed-reality learning research, which treats bodily movement and spatial representation as pedagogically meaningful only when tied to learning content and supported by design [33].

C. Hybrid Scaffolding Is Necessary

XR sound pedagogy in this workshop required hybrid scaffolding: participants had to learn headset use, mixed-reality interaction, OSL operation and modular synthesis in a compressed format, while onboarding, nausea, optical clarity and underdeveloped production features directly shaped the learning situation. The absence of passthrough depth occlusion may also have contributed to visual strain and fatigue, because virtual objects were visually layered over the physical room and participants' hands rather than being hidden by them.

The tactile gap should also be treated as part of this scaffolding problem. Physical modular synthesis is a material practice of knobs, cables, resistance, weight and touch. OSL offered controller-based manipulation and partial haptic feedback, but these only partially replace that materiality, as one participant's explicit wish to touch the virtual objects made clear.

Comfort, exposure duration and headset setup should be treated as pedagogical design variables rather than implementation details. This aligns with XR learning literature that treats immersion as mediated by presence, agency, cognitive load, self-regulation and comfort rather than as automatically beneficial [34]–[36]. It also aligns with modular pedagogy sources that emphasize accessible tools, staged exercises, short scaffolds, collaborative patching and student presentation as conditions for learning technically demanding sound practices [2], [29], [37]. OSL's spatial strengths appear most useful when participants have enough support to treat space as a sound-design resource rather than as an additional obstacle.

D. Position in XR Sound Pedagogy

The case contributes to research on XR sound and music practices by documenting a multi-day class-scale workshop in which a shared mixed-reality sound system was used for teaching, making, mentoring and presentation. OSL was not only the object of instruction but also the workshop environment, connecting shared networked state, co-located interaction, spatial sound-design work and public presentation.

Read against the work reviewed above, the main contribution is to move from task comparison or interface description into a sustained studio-workshop setting. In this setting, spatial and social presence were clearly valuable, but they did not automatically produce fluent interaction, learning autonomy or sustained collaboration. The same system that made patches

visible, walkable and shareable also introduced onboarding, comfort, optical, editing, recording and social-legibility constraints. The workshop therefore shows that shared MR sound environments need to be designed as pedagogical infrastructures, not only as expressive tools.

The case also qualifies earlier claims about XR modular synthesis [11]: spatial organization, direct manipulation and shared practice transferred into the workshop far more convincingly than tactile materiality.

VIII. DESIGN AND PEDAGOGICAL IMPLICATIONS

The case points to four design and teaching implications. First, headset onboarding should be treated as a separate pedagogical phase. Because many students still have little or no XR experience, future workshops should include one-to-one onboarding time before sound-design teaching begins. The lecturer should be able to see what each student sees by casting or mirroring the headset view to a smartphone or computer, especially before the OSL app and its networked synchronization are running. Comfort, fit and visual clarity also need to be checked reliably.

Second, the modular synthesis curriculum should be reduced in complexity or distributed over a longer format, such as a full semester rather than a five-day workshop. Visualizations should carry more of this scaffolding. Newer OSL development already points in this direction: patch cables can visualize the signal they carry, with red for positive values, black for zero and blue for negative values. This kind of immediate visual feedback can make the dynamics of a full patch more legible while students listen and edit. This follows modular pedagogy accounts that treat signal-flow visualization, tutorial scaffolds and presentation of patches as central learning supports [1], [2], [29].

Third, co-located collaboration should be treated as both a working affordance and a workshop-design variable. In technical terms, shared patching was functional, but most participants chose individual or personal-session work. This is a valid personal working style and should not be read simply as a failure of the collaborative system. For future research, however, collaboration should be structured more explicitly if it is to be evaluated. Future workshops could assign at least one structured paired patching task, one scheduled peer-visit round and short critique rounds before final presentations.

Fourth, the next study should be designed before the workshop begins rather than added retrospectively. It should include pre- and post-workshop self-assessments, comfort and exposure logs, structured reflections, targeted interviews and systematic video coding. These data would help separate engagement from learning transfer, connect fatigue or visual issues to exposure time or other factors, and analyze collaboration, peer visits and spatial scaffolding more deeply.

IX. CONCLUSION

This paper examined the September 2024 OSL workshop as a formative case study of mixed-reality sound-design pedagogy. The workshop shows how a shared MR modular environment can function as pedagogical infrastructure rather than

only as an interface: guided instruction, personal patching, peer visits, mentoring and final presentation all took place inside the same spatial sound system.

Within this bounded case, OSL's strongest affordances were spatial organization, shared patch visibility, multiplayer presence and performable artifacts. Participants translated guided instruction into laboratory experiments, collaborative patches, performance interfaces, installation-like works, spatial diagrams and site-specific binaural sound. These outcomes suggest that OSL's pedagogical value lies in making signal flow, spatial audio and project artifacts visible, walkable and discussable.

The case is not a validation claim. It does not prove that mixed reality improves sound-design learning or should replace DAWs, hardware instruments or established studio teaching. Spatial and social presence coexisted with interrupted flow, headset onboarding, nausea, optical limitations, beginner scaffolding demands, partial tactile transfer and uneven collaboration. For research communities interested in XR music, sound and interaction practices, the contribution is a concrete workshop format that shows both the promise and the design burden of co-located mixed-reality sound pedagogy.

X. OUTLOOK

Since the September 2024 workshop, OSL has continued to develop, including work on alias-free sound quality, polyrhythm and polymeter sequencing, directivity and occlusion for spatialized sources as well as 3rd-order Ambisonics playback and recording based on Resonance Audio, robust automatic co-location using AprilTag fiducials, Ableton Link integration, and passthrough depth occlusion. These developments provide material for future media-arts teaching experiments and follow-up studies. For reproducibility and further inspection, OSL is available as source code at GitHub, as an archived software snapshot on Zenodo and as a binary from the Meta Quest Store.

DISCLOSURE OF AI-ASSISTED WRITING

AI-assisted tools were used to support literature research, source organization and writing. The author conducted the analysis and interpretation, verified all factual statements and claims and remains responsible for the content of the paper.

REFERENCES

- [1] P.-A. Gauthier and S. Claude, "Considerations on a workshop on modular synthesis for audio arts," *eContact!*, vol. 17, no. 4, 2016, analogue and Modular Synthesis: Resurgence and Evolution. Montréal: Communauté électroacoustique canadienne / Canadian Electroacoustic Community. https://econtact.ca/17_4/gauthier-claude_modularworkshop.html.
- [2] A. Fox and J. C. Wu, "Teaching modular synth & sound design online during COVID-19: Maximizing learning outcomes through open-source software and student-centered pedagogy," in *Proceedings of the 151st Audio Engineering Society Convention*. Online: Audio Engineering Society, Oct. 2021, convention Paper 10511. <https://aes2.org/publications/elibrary-page/?id=21475>.
- [3] A. Boem and L. Turchet, "Musical metaverse playgrounds: Exploring the design of shared virtual sonic experiences on web browsers," in *2023 4th International Symposium on the Internet of Sounds*. IEEE, 2023, pp. 1–9, <https://doi.org/10.1109/IEEECONF59510.2023.10335297>.
- [4] A. Boem, D. Dziwis, M. Tomasetti, S. Etezazi, and L. Turchet, "'It Takes Two' - shared and collaborative virtual musical instruments in the musical metaverse," in *2024 IEEE 5th International Symposium on the Internet of Sounds*. IEEE, 2024, pp. 1–10, <https://doi.org/10.1109/IS262782.2024.10704079>.
- [5] L. Bruns, B. Saurbier, T. M. Voong, and M. Oehler, "Presence and flow in virtual and mixed realities for music-related educational settings," in *2024 IEEE 5th International Symposium on the Internet of Sounds*. IEEE, 2024, pp. 1–7, <https://doi.org/10.1109/IS262782.2024.10704115>.
- [6] L. Bruns, B. Saurbier, T. M. Voong, W. Blume, T. Rotsch, and M. Oehler, "Comparing singing lessons in mixed reality, video and in-person," in *2025 IEEE 6th International Symposium on the Internet of Sounds*. IEEE, 2025, pp. 1–10, <https://doi.org/10.1109/IS264627.2025.11284551>.
- [7] M. Buffa, D. Girard, and A. Hofr, "Using web audio modules for immersive audio collaboration in the musical metaverse," in *2024 IEEE 5th International Symposium on the Internet of Sounds*. IEEE, 2024, pp. 1–10, <https://doi.org/10.1109/IS262782.2024.10704108>.
- [8] M. Buffa, M. Winckler, Q. Escobar, S. Demont, A. Hofr, and A. Mir-Sadjadi, "Interactive audio sculpting: Plugin customization and UI affordances in immersive environments," in *2025 IEEE 6th International Symposium on the Internet of Sounds*. IEEE, 2025, pp. 1–10, <https://doi.org/10.1109/IS264627.2025.11284559>.
- [9] M. Flores Vargas, R. Connolly, E. Bates, and R. McDonnell, "Immersive vocal practice: Audio-visual evaluation of an acoustic virtual environment for vocal rehearsal and performance," in *2025 IEEE 6th International Symposium on the Internet of Sounds*. IEEE, 2025, pp. 1–10, <https://doi.org/10.1109/IS264627.2025.11284625>.
- [10] L. Zeller and H. Barfuss, "OpenSoundLab – a virtual sound laboratory for the arts," in *AudioMostly 2022*. New York: Association for Computing Machinery, 2022, pp. 159–162, <https://doi.org/10.1145/3561212.3561249>.
- [11] L. Zeller and C. E. Leisi, "Modular observers: OpenSoundLab and PatchWorld as case studies for emerging practices of modular synthesis in extended realities," *Organised Sound*, pp. 1–12, 2026, <https://doi.org/10.1017/S1355771826101216>.
- [12] L. Zeller and A. Bauer, "The walkable instrument: Modular patches as entangled environments in OpenSoundLab," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, Canberra, Australia, 2025, <https://doi.org/10.5281/zenodo.17802609>.
- [13] L. Zeller, "Video documentation for the spark project 'Emerging Practices in Modular Synthesis: Towards a Virtual Ethnography for Mixed Realities,'" Zenodo, 2024, version v2, containing *CoCreate.mp4*. <https://doi.org/10.5281/zenodo.15771993>.
- [14] A. Parente La Selva, I. Marouda, and P.-J. Maes, "Sonic metaverses of Odin and LUME theater laboratories: From embodied knowledge to collective memories," in *2025 IEEE 6th International Symposium on the Internet of Sounds*. IEEE, 2025, pp. 1–7, <https://doi.org/10.1109/IS264627.2025.11284574>.
- [15] L. Bruns and T. Rotsch, "XR-Producing im Musikunterricht: Didaktisches Design im Projekt LEVIKO-XR am Beispiel 'Kollaboratives Musik Erfinden zu Mood Clips in der XR-Anwendung PatchWorld,'" *MedienPädagogik*, vol. 68, pp. 171–195, 2026, <https://doi.org/10.21240/mpaed/68/2026.01.27.X>.
- [16] PatchXR, "Teaching music inside virtual worlds," 2026, <https://patchxr.com/blog/xr-music-education-patchworld-leviko/>.
- [17] L. Turchet, "Musical metaverse: Vision, opportunities, and challenges," *Personal and Ubiquitous Computing*, vol. 27, no. 5, pp. 1811–1827, 2023, <https://doi.org/10.1007/s00779-023-01708-1>.
- [18] T. Hopkins, S.-Y. Ma, S. C.-C. Weng, M.-Y. Pai, E. Y.-L. Do, and L. Turchet, "MR-DAW: Towards collaborative digital audio workstations in mixed reality," in *2025 IEEE 6th International Symposium on the Internet of Sounds*. IEEE, 2025, pp. 1–10, <https://doi.org/10.1109/IS264627.2025.11284566>.
- [19] D. Dziwis, H. von Coler, and C. Porschmann, "Live coding in the metaverse," in *2023 4th International Symposium on the Internet of Sounds*. IEEE, 2023, pp. 1–8, <https://doi.org/10.1109/IEEECONF59510.2023.10335358>.
- [20] G. Wakefield, M. Palumbo, and A. Zonta, "Affordances and constraints of modular synthesis in virtual reality," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2020, pp. 547–550, <https://doi.org/10.5281/zenodo.4813182>.
- [21] D. A. Schön, *The Design Studio: An Exploration of Its Traditions and Potentials*. London: RIBA Publications, 1985.

- [22] A. Shreeve, E. Sims, and P. Trowler, ““A Kind of Exchange”: Learning from art and design teaching,” *Higher Education Research & Development*, vol. 29, no. 2, pp. 125–138, 2010, <https://doi.org/10.1080/07294360903384269>.
- [23] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, “Motivating project-based learning: Sustaining the doing, supporting the learning,” *Educational Psychologist*, vol. 26, no. 3–4, pp. 369–398, 1991, <https://doi.org/10.1080/00461520.1991.9653139>.
- [24] B. J. S. Barron, D. L. Schwartz, N. J. Vye, A. Moore, A. Petrosino, L. Zech, and J. D. Bransford, “Doing with understanding: Lessons from research on problem- and project-based learning,” *The Journal of the Learning Sciences*, vol. 7, no. 3–4, pp. 271–311, 1998, <https://doi.org/10.1080/10508406.1998.9672056>.
- [25] D. Kokotsaki, V. Menzies, and A. Wiggins, “Project-based learning: A review of the literature,” *Improving Schools*, vol. 19, no. 3, pp. 267–277, 2016, <https://doi.org/10.1177/1365480216659733>.
- [26] I. Harel and S. Papert, Eds., *Constructionism: Research Reports and Essays, 1985–1990*. Norwood, NJ: Ablex, 1991.
- [27] K. M. Sheridan, E. R. Halverson, B. K. Litts, L. Brahms, L. Jacobs-Priebe, and T. Owens, “Learning in the making: A comparative case study of three makerspaces,” *Harvard Educational Review*, vol. 84, no. 4, pp. 505–531, 2014, <https://doi.org/10.17763/haer.84.4.brr34733723j648u>.
- [28] K. Thumlert, J. Nolan, M. McBride, and H. Chan, “Strange play: Parametric design and modular learning,” in *Modular Synthesis: Patching Machines and People*, E. J. Teboul, A. Kitzmann, and E. Engström, Eds. Abingdon, Oxon and New York: Focal Press, 2024, pp. 185–204, <https://doi.org/10.4324/9781003219484-10>.
- [29] P.-L. Lecours and M. Gagnon-Legault, “Interpretation and learning of modular synthesis: Three studies,” in *Proceedings of the International Conference on Technologies for Music Notation and Representation – TENOR’25*, Y. Zhang, Ed. Beijing, China: Digital Score Lab, Central Conservatory of Music, 2025, pp. 222–230, https://www.tenor-conference.org/proceedings/2025/25_TENOR2025_Pierre-Luc_Lecours.pdf.
- [30] L. Zeller, “Tutorials,” OpenSoundLab YouTube channel, playlist, 2025, updated Dec. 3, 2025. <https://www.youtube.com/playlist?list=PLSnuTstoP7nDSK8XqfTnln1v3dH0jACu7>, accessed Sep. 8, 2026.
- [31] C. E. Leisi and O. Sahli, “Co-experiencing virtual spaces: A standalone multiuser virtual reality framework,” Zenodo, Tech. Rep., 2020, <https://doi.org/10.5281/zenodo.4399217>.
- [32] R. K. Yin, *Case Study Research and Applications: Design and Methods*, 6th ed. Thousand Oaks, CA: SAGE, 2018.
- [33] R. Lindgren and M. Johnson-Glenberg, “Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality,” *Educational Researcher*, vol. 42, no. 8, pp. 445–452, 2013, <https://doi.org/10.3102/0013189X13511661>.
- [34] L. Jensen and F. Konradsen, “A review of the use of virtual reality head-mounted displays in education and training,” *Education and Information Technologies*, vol. 23, no. 4, pp. 1515–1529, 2018, <https://doi.org/10.1007/s10639-017-9676-0>.
- [35] G. Makransky and G. B. Petersen, “The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality,” *Educational Psychology Review*, vol. 33, no. 3, pp. 937–958, 2021, <https://doi.org/10.1007/s10648-020-09586-2>.
- [36] S. Weech, S. Kenny, and M. Barnett-Cowan, “Presence and cybersickness in virtual reality are negatively related: A review,” *Frontiers in Psychology*, vol. 10, 2019, Art. no. 158. <https://doi.org/10.3389/fpsyg.2019.00158>.
- [37] C. Dobrian, “Introducing computer music in secondary school,” in *Proceedings of the Journées d’Informatique Musicale (JIM 2023)*, Saint-Denis, France, 2023, <https://music.arts.uci.edu/dobrian/DobrianJIM2023.pdf>.