Emil Polyak

SELECTED CREATIVE WORKS AND PUBLICATIONS

(Extended)

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Digital Fidget: Harnessing Janus Particle Dynamics for Ambiguous Tangible Interfaces in Creative Ideation (patent pending)

EMIL POLYAK

Fig. 1. Digital Fidget. A crocheted sack (~160 mm) contains a sealed 70 mm PVC sphere with 12 copper electrodes. Thousands of 6 mm Janus spheres (half carbon-coated) tumble during manipulation and continuously reshape the capacitive field.

We present *Digital Fidget*, a novel tangible interface that exploits the intrinsically anisotropic electrical properties of *Janus spheres* to create an ambiguous yet meaningful input modality for creative ideation. Unlike stochastic noise generators or conventional precision-based interfaces, our system leverages hemispheric conductivity gradients: thousands of half-coated conductive *millimeter-scale* spheres self-organize into dynamic electrical pathways to produce input patterns that exist in the liminal space between order and chaos. This positions our work at the intersection of tangible computing and ambiguous design, addressing the phenomenological need for interfaces that support pre-conceptual imagination states essential to creative practice.

CCS Concepts: • **Human-centered computing** → **Interaction devices**; • **Hardware** → Sensor devices and platforms; • **Applied computing** → *Media arts*.

Additional Key Words and Phrases: tangible interfaces, capacitive sensing, Janus spheres, ambiguous input, creative ideation, embodied interaction

1 Introduction

Early ideation benefits from *structured ambiguity*: signals that invite interpretation without collapsing into either noise or precision control. Prior HCI work positions ambiguity as a resource for sense-making and engagement [5], while studies link pareidolia and tolerance for ambiguity with creative potential [1, 10]. We define structured ambiguity as input exhibiting temporal coherence and physical causality distinct from both deterministic precision and memoryless randomness where current states influence but don't determine future possibilities. *Digital Fidget* pursues this space using Janus spheres—6 mm PLA spheres half-coated with carbon conductive paint—whose hemispheric conductivity redirects capacitive field lines as they jostle, align, and part. The resulting signal exhibits this coherence alongside surprise without requiring cameras or precise gestures. We describe the device design and an interpretable sensing-and-feature pipeline, and outline a plan to evaluate engagement and interpretive use; the practical contribution is a compact, reproducible interface for ambiguous tangible input.

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2 Background and Related Work

Ambiguity can enable interpretation and discovery, and pareidolia as well as tolerance for ambiguity correlate with creative potential, motivating interfaces that sustain open-ended perception [1, 5, 10]. Capacitive systems routinely sense through dielectrics via fringing fields, and metallic–dielectric Janus spheres exhibit orientation-dependent dipoles and distinct electrokinetic responses, which we adapt at tangible scale with a multi-electrode spherical arrangement for expressive input [2, 6, 8, 9, 11].

3 System Design

A 70 mm PVC sphere houses twelve 30 mm copper electrodes positioned on an icosahedral layout for even spatial coverage. Electrodes connect to an MPR121 12-channel capacitive controller; an Adafruit ESP32 Feather (8 MB flash, 2 MB PSRAM) streams the 12-channel data via OSC at approximately 38–50 fps to a host application [3, 4]. The sphere is enclosed in a crocheted sack (~160 mm) filled with thousands of 6 mm PLA Janus spheres: one hemisphere is coated with a carbon-based conductive paint (MG 838AR), the other hemisphere remains uncoated [7]. As the user manipulates the sack, the Janus spheres rearrange and reorient, repeatedly altering field paths inside the enclosure.

4 Methodology

4.1 Sensing Principle

Janus spheres have hemispheric conductivity. As they rotate and contact one another and the enclosure, they redirect and concentrate capacitive field lines moment to moment. The twelve electrodes register these changes through the PVC shell as evolving capacitance patterns. Because the enclosure is a dielectric, fringing fields pass through it, enabling a fully sealed sensor without optics or moving contacts. The icosahedral electrode geometry provides even directional coverage with modest channel count.

4.2 Feature Extraction and Mapping

A lightweight Python bridge receives the OSC stream and normalizes samples into per-channel activations after a brief baseline. We compute *turbulence* (how rapidly and how unevenly channels change), entropy (concentrated versus dispersed activity), a 3D *spatial centroid* and *spread* (where activity concentrates and how broadly), and a short-window *spatial fingerprint* of sustained activation; recurring fingerprints support recognition of repeated behaviors without predefined labels. An optional unsupervised stage groups motifs, and a regularized continuous mapping drives audiovisual parameters. Mappings are deliberately simple and transparent to preserve the device's ambiguous, exploratory character.

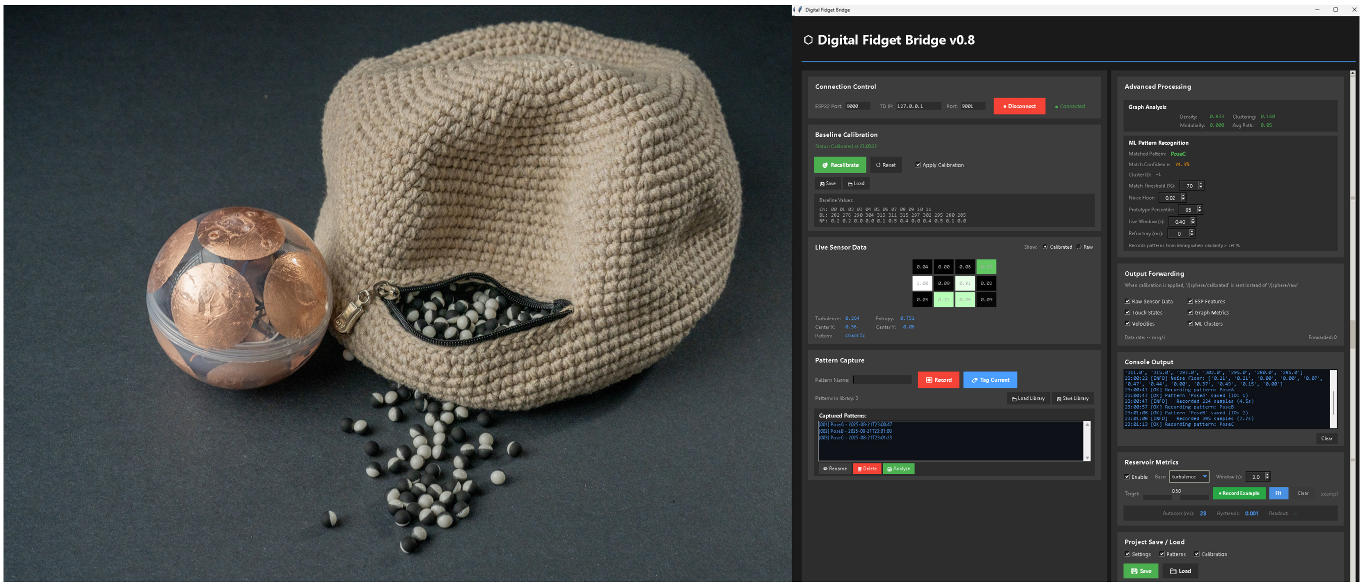

Fig. 2. Digital Fidget hardware and software components. Left: Internal sphere assembly with icosahedrally-arranged copper electrodes, MPR121 capacitive controller, and ESP32 Feather microcontroller housed within the PVC shell, surrounded by conductive Janus spheres. Right: Custom-developed Python interface for real-time feature extraction and visualization, displaying turbulence, entropy, spatial centroid, and activation patterns from the 12-channel capacitive sensor array.

5 Planned Evaluation

We will run lab sessions with creative-technology students and designers. Sessions will include open-ended interaction blocks, brief interviews, and short creativity-adjacent probes such as interpreting abstract visuals driven by the participant's own interactions. Primary observations will concern sustained engagement, the emergence of personal gestural vocabularies, and pareidolic reports; logs of feature trajectories will contextualize qualitative accounts. Results are beyond the scope of this poster.

6 Applications and Future Directions

Digital Fidget functions as an ideation aid that sustains structured ambiguity in early creative work, where exploration is more valuable than precision. It also suggests calming, non-goal-oriented interaction for therapeutic or mindfulness contexts, and offers expressive access when precise targeting is difficult, since the system adapts to whatever movement the user can provide. Future directions include comparative studies of coating materials and packing densities to tune experiential qualities; alternative electrode geometries and shell dielectrics for sensitivity shaping; multi-device linking for collaborative sessions in which one device's state seeds another's generative context; and a formal evaluation of engagement duration, emergence of personal gestural vocabularies, and pareidolic reports, supported by feature-trajectory logs.

7 Discussion and Limitations

The device aims to provide responsive ambiguity rather than randomness: short-term hysteresis emerges from friction, inertia, intermittent contacts, settling, and occasional residual charge, so present configurations constrain near-future states and produce temporal coherence distinct from memoryless pseudorandomness. Practical limitations include environmental capacitance and static affecting baselines, sensitivity tuning across materials and packing density, and long-term coating durability; these are engineering parameters rather than conceptual constraints.

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3D Gaussian Splat of Jack Lenor Larsen's Study

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Abstract. This research explores the application of 3D Gaussian Splatting (3DGS) as an alternative computational photogrammetry method for documenting complex interior spaces containing cultural artifacts. The study focuses on Jack Lenor Larsen's personal study at LongHouse Reserve, where diverse textiles, furniture, and Indigenous crafts create a challenging environment for traditional 3D capture due to mixed lighting conditions and material complexity. The methodology employed COLMAP for initial sparse reconstruction through structure-from-motion (SfM), followed by conversion to dense 3DGS modeling using PostShot software. The resulting point cloud was refined using CloudCompare and visualized through Supersplat for real-time web-based exploration. The final model achieved a Structural Similarity Index of 0.811, demonstrating adequate capture of intricate spatial relationships and material details. This approach successfully preserves the contextual significance of artifacts within their original environment, enabling virtual visitors to examine objects in situ while maintaining the immersive quality.

Keywords: 3D Gaussian Splatting, Cultural heritage, Photogrammetry, Digital preservation, Virtual museums

1 Introduction

The preservation of cultural heritage through digital documentation has emerged as a critical intersection between computational methods and humanistic inquiry, particularly as institutions grapple with the dual imperatives of conservation and accessibility. While traditional photogrammetry has established itself as a cornerstone technology for three-dimensional capture of architectural spaces and artifacts, the documentation of complex interior environments presents unique challenges that demand innovative approaches. These challenges become particularly acute when attempting to preserve spaces that function not merely as containers for objects, but as carefully curated environments where the spatial relationships between artifacts constitute essential aspects of their cultural significance.

The advent of Neural Radiance Fields (NeRF) (Mildenhall et al., 2020) and its subsequent evolution into 3D Gaussian Splatting (3DGS) (Kerbl et al., 2023) represents a paradigm shift in computational approaches to three-dimensional scene reconstruction. Unlike traditional photogrammetric methods that rely on discrete point clouds or mesh-based representations, 3DGS employs a continuous volumetric representation through anisotropic Gaussian primitives, enabling the capture of complex lighting conditions, semi-transparent materials, and intricate surface details that often characterize culturally significant interior spaces. This novel approach offers particular promise for heritage documentation, where the phenomenological qualities of space, the interplay of light, shadow, texture, and material constitute integral components of cultural meaning that traditional capture methods frequently fail to preserve.

Jack Lenor Larsen's personal study at LongHouse Reserve in East Hampton, New York, presents an exemplary case for examining the capabilities of 3DGS in heritage documentation. As the private workspace of one of the twentieth century's most influential textile designers (Grimes, 2020), the study embodies a complex assemblage of diverse materials, textures, and cultural artifacts that reflect Larsen's extensive travels and cross-cultural design philosophy. The space contains an intricate arrangement of handwoven textiles, indigenous crafts, modernist furniture, and personal memorabilia, creating a dense visual environment where conventional photogrammetric approaches struggle to maintain fidelity across the heterogeneous material palette and varying scales of detail.

The technical challenges inherent in documenting such spaces extend beyond mere geometric reconstruction. Traditional structure-from-motion (SfM) pipelines often produce incomplete or noisy reconstructions when confronted with the reflective surfaces of glass display cases, the translucency of fabric installations, or the complex interplay of natural and artificial lighting that characterizes museum-quality interior spaces. Moreover, the computational demands of processing high-resolution imagery through conventional photogrammetric workflows can prove prohibitive for institutions seeking to implement digital preservation strategies at scale. The emergence of 3DGS offers a potential solution to these limitations through its efficient rendering pipeline and ability to interpolate between captured viewpoints while maintaining photorealistic quality.

This research investigates the application of 3DGS as an alternative methodology for documenting culturally significant interior spaces, using Larsen's study as a test case to evaluate the technology's capacity to preserve both the geometric accuracy and experiential qualities essential to heritage documentation. The study employs a hybrid workflow that leverages established SfM techniques for initial camera pose estimation through COLMAP (Schönberger & Frahm, 2016), followed by conversion to the 3DGS representation using PostShot software. This approach seeks to balance computational efficiency with reconstruction quality, while maintaining compatibility with existing digital heritage infrastructure and workflows (UNESCO, 2003).

The significance of this investigation extends beyond technical innovation to address fundamental questions about the nature of digital preservation in cultural heritage contexts. As institutions increasingly recognize the limitations of object-centric documentation approaches that divorce artifacts from their contextual environments, the need for methodologies capable of preserving spatial relationships and atmospheric qualities becomes paramount. The Larsen study, with its carefully orchestrated interplay of objects, lighting, and spatial composition, exemplifies the type of culturally rich environment where traditional documentation methods fall short of capturing the essential qualities that constitute its heritage value.

Furthermore, the development of web-based visualization platforms for 3DGS models, opens new possibilities for remote access to heritage sites, enabling scholarly research and public engagement without the physical constraints or conservation concerns associated with on-site visitation. This democratization of access aligns with contemporary museum practices that seek to expand audience reach while maintaining preservation standards, particularly relevant in the post-pandemic context where digital engagement has become essential to institutional sustainability.

2 Methodology

The documentation of Jack Lenor Larsen's study required a carefully orchestrated acquisition and processing pipeline designed to address the specific challenges posed by the space's material heterogeneity and complex illumination conditions. The methodology employed a hybrid approach that leveraged the complementary strengths of established photogrammetric techniques and emerging neural rendering methods, with particular attention to preserving the perceptual qualities.

2.1 Data Acquisition Protocol

Image capture was performed using a Sony A7R IV full-frame mirrorless camera paired with a Sony G Master 24mm f/1.4 prime lens, chosen for its minimal distortion and exceptional edge-to-edge sharpness features, especially valuable in confined interior spaces. To ensure comprehensive spatial coverage and material fidelity, we implemented a hybrid acquisition workflow combining high-resolution RAW photographs with 4K video footage recorded in a flat S-Log3 gamma profile. This dual-source strategy allowed us to extract high-quality stills from the video sequence.

Figure 1. Natural light enters from the east-facing window, interacting with a low color temperature wall fixture above the tiled fireplace. Source: Authors, 2025.

To ensure consistency across all source imagery, a 24-patch X-Rite ColorChecker target was introduced at various stages of the shoot. This enabled precise color calibration of both video frames and photographs, allowing us to match chromatic values across modalities during post-processing. Manual camera settings were used throughout: aperture and shutter speed were fixed based on ambient light levels, white balance was locked to prevent automatic temperature drift, and focus was manually set to achieve maximum depth of field across each shot. No flash was used at any point, eliminating the risk of glare or overexposure that could compromise material accuracy or damage sensitive objects. The documentation process adhered to heritage imaging best practices, ensuring minimal disruption to the environment and fidelity to original materials, as emphasized in established cultural heritage photogrammetry guidelines (Historic England, 2017).

The room’s lighting environment combined indirect natural daylight from an east-facing window with localized warm-toned tungsten fixtures, producing a heterogeneous illumination scheme with shifting color temperatures and varying shadow gradients. To stabilize contrast ratios and minimize underexposure in occluded areas such as corners, under shelving, or shadowed sides of objects, we employed two color-calibrated LED softboxes positioned off-axis and set to low intensity. These constant-light sources provided a neutral 5600K fill without overwhelming the ambient tone, ensuring that additional illumination preserved the perceptual atmosphere of the space. Their diffuse character minimized hard shadows and avoided introducing unwanted specular highlights, which could interfere with photogrammetric alignment or alter the perceived surface properties of gloss-sensitive materials.

Figure 2. This visualization shows the reconstructed camera positions and orientations relative to the sparse point cloud, providing insight into the capture strategy. Source: Authors, 2025.

Acquisition proceeded along a structured sequence designed for maximum coverage with robust parallax: orbital passes around artifact clusters were paired with perimeter sweeps at three elevations, knee-level, eye-level, and overhead. Still images were captured at roughly 20–30 degree intervals, maintaining at least 70–85% overlap across frames to facilitate reliable tie-point generation during structure-from-motion processing. Special attention was given to view-dependent or visually ambiguous materials, such as reflective ceramics and semi-translucent fibers, which were recorded at multiple oblique angles to ensure volumetric detail and to aid the subsequent modeling of anisotropic highlights and subsurface light behavior.

The final dataset consisted of over 300 RAW photographs and a curated set of sharp, color-corrected frames extracted from video, selected for their complementary viewpoints and fidelity. These were combined during reconstruction to maximize completeness and minimize reconstruction gaps, particularly in zones where texture uniformity, occlusion, or dynamic lighting would otherwise lead to failure in standard single-source workflows.

2.2 Material Properties and Perceptual Considerations

The physical composition and spatial arrangement of Jack Lenor Larsen’s study introduced material and perceptual challenges beyond those encountered in more controlled photogrammetric contexts. The room is densely layered with baskets, books, ceramics, textiles, and lacquered surfaces, composed into an immersive and intentionally congested interior. This density limited clear camera sightlines, resulting in occlusion and restricted viewpoints. The compact geometry further constrained movement and elevation shifts, especially for artifacts placed low to the ground, requiring deliberate coverage strategies to maintain adequate parallax and completeness.

The lighting was uneven and spectrally mixed. A large window introduced cool, directional daylight across the room, while the warm tungsten fixture filled the rest with a diffused glow. This combination led to localized color shifts and contrast gradients, particularly where light types intersected across reflective surfaces. Dark-glazed ceramics and UV-reactive book covers proved especially difficult to expose consistently. Color calibration using the 24-patch ColorChecker minimized chromatic drift; however, certain tonal inconsistencies remained visible in sequences involving transitional zones or glossy materials.

Reflective and refractive surfaces such as lacquered tabletops, polished ceramics, and varnished wood exhibited specular highlights that shifted significantly across views. These interfered with feature matching in structure-from-motion, often causing fragmentation or surface drift. Oblique-angle coverage allowed more consistent triangulation by reducing the impact of these transient effects.

In contrast, objects with broad, low-contrast textures, wicker baskets, unpatterned cloth, and hand-bound books did not produce enough high-frequency detail for confident matching. While not entirely smooth, their surfaces lacked the distinct microgeometry favored by photogrammetric pipelines. Some appeared softened or slightly irregular in the final point cloud. These limitations underscore the difficulty of digitally reconstructing perceptual materiality, where light, texture, and form interact in ways not easily abstracted into geometry. Although dense coverage mitigated most omissions, it was the view-dependent appearance modeling in the 3D Gaussian Splatting stage that most effectively preserved visual coherence, capturing surface sheen, layering of shadows, and the interior's cohesive spatial logic.

2.3 Structure-from-Motion and 3D Gaussian Splatting

Initial 3D reconstruction was performed using COLMAP's hierarchical structure-from-motion pipeline to solve for camera poses and generate a sparse point cloud. Feature detection parameters were tuned for indoor low-texture scenes, with an increased threshold for SIFT keypoint density and spatial verification enabled to filter out false matches caused by repetitive patterns in rugs and textile motifs. Manual intervention was occasionally required to reconcile partial reconstructions, particularly in the vicinity of reflective display cases and high-glare furniture tops.

Figure 3. The point cloud generated through Structure from Motion reveals the spatial complexity of the study room. Source: Authors, 2025.

The resulting camera poses and point cloud were then processed via PostShot, a 3DGS preprocessing tool that trains imagery into a radiance field composed of anisotropic Gaussian primitives. Optimization was performed in two phases: an initial coarse pass to establish global geometry and a subsequent fine-tuning phase for appearance and detail refinement. The Gaussian splats were optimized with regularization parameters that balanced opacity coherence, scale stability, and spatial density, with additional refinement layers applied to surfaces exhibiting thin geometry or reflective interference.

The final splat model consisted of ~1.2 million Gaussians and was deployed using Supersplat, enabling real-time web-based rendering. Supersplat's level-of-detail rendering was configured to prioritize high-contribution Gaussians along major gaze vectors, maintaining perceptual consistency during interaction. Importantly, the model retained spherical harmonic lighting representations to preserve specular anisotropy, a critical factor in communicating the material realism of the environment.

2.4 Point Cloud Refinement

Following the optimization of the Gaussian splat model, we performed a targeted refinement process to remove noise and artifacts introduced during reconstruction. A critical step involved exporting the point-based 3DGS data for cleanup in CloudCompare, which offers a suite of high-precision filtering tools not currently available in the core 3DGS pipeline.

Figure 4. A detailed look at the central seating area after optimization in CloudCompare, where statistical outlier removal and cleanup were applied. Source: Authors, 2025.

Within CloudCompare, we applied statistical outlier removal, calibrated to eliminate high-deviation points based on local neighborhood density. This effectively removed stray points and reconstruction artifacts, including common floaters generated near reflective surfaces or low-coverage regions during Gaussian optimization. Particular attention was given to preserving high-frequency geometric structures, the edges of objects, and the profiles of stacked objects, which were sometimes partially surrounded by splatting-induced noise. After filtering, the cleaned point cloud was converted back into 3DGS-compatible format, with full reactivation of the Gaussian parameters required for real-time rendering.

3 Results

3.1 Structural Similarity Index (SSIM) as a Quality Metric

One of the quantitative measures we obtained from the reconstruction is the Structural Similarity Index (SSIM). SSIM is a perceptual image quality metric that compares two images (typically a reconstructed image vs. a reference) in terms of luminance, contrast, and structural details. Unlike simple pixel-wise differences, SSIM was designed to better correlate with human visual perception of image fidelity. An SSIM value ranges from -1 to 1, where 1.0 indicates a perfect match (structurally and visually) between images.

Figure 5. The interior space is generated from sparse point cloud data using 3D Gaussian Splatting. Source: Authors, 2025.

It's worth noting, however, that SSIM alone does not tell the whole story of visual quality. SSIM is computed against whatever reference images we have; if the dataset lacks certain angles or lighting conditions, SSIM might not penalize some artifacts that are perceptually obvious in novel views. Moreover, while SSIM generally aligns better with human judgment than raw error metrics, there can still be differences between the SSIM score and what a human observer would deem "realistic". In our case, the SSIM score of 0.811 showing up in Postshot gives a rough idea of reconstruction fidelity, but we also critically assess perceptual fidelity by eye, especially for how well the objects blend into their environment.

3.2 Importance of Contextual Perceptual Fidelity

Ultimately, our goal is high perceptual fidelity; the reconstruction should look convincing to a human observer. Importantly, this fidelity must hold in the context of the object's environment, not just for the object in isolation. In this case, the room itself, the study of Jack Lenor Larsen, is not merely a container for valuable artifacts but a site of lived curatorial expression. The way Larsen arranged, lit, and inhabited these objects is inseparable from their cultural meaning. The reconstruction must therefore capture not just the objects themselves but the spatial and atmospheric relationships that shaped how they were experienced. A 3D artifact should appear as it would in its real setting, surrounded by other objects, immersed in ambient room lighting, and shaped by accumulated layers of texture, use, and proximity. Fidelity to this context is a tougher benchmark: an object might appear visually accurate on its own yet still feel "off" if its lighting, boundaries, or spatial relationships are disconnected.

Figure 6. This secondary perspective highlights the spatial coherence and photorealistic quality achieved by 3D Gaussian Splatting. Source: Authors, 2025.

A highly detailed scan of an artifact presented under ideal studio lighting may be visually clean, but when reintroduced into a virtual rendering of its original setting, mismatches in scale, tone, or lighting may disrupt the authenticity of the experience. This is why we emphasize contextual realism, ensuring that each element contributes to a coherent and truthful representation of the scene as a whole, preserving the integrity of how the space was inhabited and how meaning was constructed through placement and proximity.

Another challenge is that we lack direct comparative data or ground-truth for certain aspects of perceptual quality. We do not have an alternate reconstruction method's output or a perfect reference model of the entire room for side-by-side comparison. As a result, our evaluation leans on metrics like SSIM and on qualitative judgments of realism. This makes perceptual fidelity even more crucial: we trust our eyes to catch issues that metrics might miss. The overall scene impression – does the room look real and coherent when navigated virtually? – is a key success criterion beyond any single numeric score.

3.3 Current Limitations in the Reconstructed Scene

Our results in this very complex room are promising, but several clarity issues persist and highlight the limitations of the current technology. Notably, we observed unwanted "floaters", small stray bits of geometry or color that hover in space where they don't belong. These "floaters" are reconstruction artifacts often caused by imperfect geometry solving or noise in the data. They are a known issue in radiance field and point-based reconstructions.

Figure 7. Rendered 3DGS (left) and Ground Truth (right). Source: Authors, 2025.

We also encountered problems in areas that were occluded or not thoroughly photographed during capture. Portions of the room that never appeared clearly in any input image tend to be reconstructed poorly or not at all. The result can be missing surfaces or muddled details in those regions. For instance, if part of a shelf or the backside of an object was not captured from enough angles, the algorithm has to guess those areas, often leading to blobby or blurry patches. These issues manifest as a loss of clarity or holes in the 3D model. In our reconstruction, some steep angles and hidden corners of objects show noticeable degradation – a direct consequence of insufficient coverage. Ensuring complete coverage of every nook and cranny of a complex environment is difficult, and our results confirm that any gap in coverage will be a weak point in the reconstruction.

4 Discussion

This study demonstrates that 3D Gaussian Splatting has the potential to offer a viable approach for documenting cultural heritage environments where spatial relationships and material presence matter as much as object detail. In reconstructing Jack Lenor Larsen's study, the aim was to preserve the perceptual coherence of the room, how objects relate to one another, how lighting defines their surfaces, and how curatorial intent is embedded in their arrangement. The complexity of the space was not incidental; it was selected precisely to test the limits of current methods and to expose failure points that remain hidden in more straightforward scenarios. While the SSIM score offered a quantitative baseline for visual fidelity, it did not capture what was most at stake: perceptual realism in context. This high-difficulty interior aligns with comparative evidence that SfM-MVS best preserves metric geometry while NeRF/3DGS excel in contextual, view-dependent appearance; under mixed spectra and heterogeneous materials, capture settings matter, and—within London Charter/CIPA principles—our hybrid pipeline and paradata resolve to a concise rubric: maximize oblique parallax, stabilize spectra with neutral fill, and budget cleanup at occlusion seams (Clini et al., 2024; Billi et al., 2025; Rangelov et al., 2024; London Charter Initiative, 2009; Stylianidis, 2019).

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Acoustic Form: Enhancing the Design Process for Assistive Earwear Jewelry via Material-Centric Computational Sound Analysis

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Figure 1: Assistive earwear jewelry with passive sound amplification.

Abstract

This work pioneers the application of computational acoustic simulation to assistive jewelry design for hearing enhancement. While acoustic modeling has been extensively used in traditional hearing aid development and architectural acoustics, its application to jewelry-scale assistive devices represents an unexplored design space. We present the first systematic methodology integrating acoustic simulation into the design process for assistive earwear jewelry, examining how material selection influences sound propagation in our originally designed Green Voice Smart Jewelry Device. Through computational analysis of four jewelry-grade metals—silver, titanium, platinum, and white gold—we demonstrate how acoustic simulation can inform both aesthetic and functional decisions in assistive jewelry design, establishing a new paradigm where computational acoustics guides the creation of hearing assistance devices that users want to wear.

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1 Introduction

Traditional hearing aids achieve technical performance but their medical appearance discourages use [Profita et al. 2018]. Decorative covers improve acceptance yet ignore acoustics. Conversely, hearing-aid engineering leverages sophisticated modeling but rarely considers jewelry form factors. Prior work on inclusive/assistive design [Pullin 2009] and finite-element analyses for auditory prostheses [Cheng et al. 2022] focuses on conventional devices, including feedback-path modeling [Sankowsky-Rothe et al. 2020]. We bridge this gap by introducing material-centric acoustic simulation to assistive jewelry. The Green Voice ear cuff incorporates internal channels intended to guide incident sound toward a capsule location while retaining an aesthetic, wearable form.

Computational analysis is particularly valuable for jewelry-scale devices, where physical prototyping in precious metals would be prohibitively expensive. Our simulation-first approach enables exploration of multiple materials—including platinum and gold alloys—without fabrication costs, allowing designers to make informed material decisions before committing to production.

2 Method

2.1 Framework

We used Treble's hybrid acoustic engine, combining a wave-based discontinuous Galerkin solver for low frequencies with a ray-based (geometrical acoustics) solver at higher frequencies [Treble Technologies 2024]. This enabled full-spectrum modeling—capturing diffraction and interference—while maintaining computational efficiency. We note that Treble was initially developed for room-scale

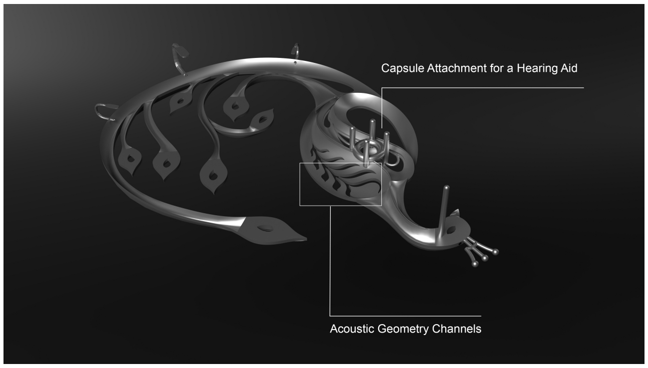

Figure 2: Green Voice ear cuff with internal channels guiding sound toward a receiver location.

acoustics, and adapting it to millimeter jewelry-scale presents some limitations.

2.2 Simulation Setup

The frequency sweep covered 250 Hz–8 kHz. A plane-wave source at 30 cm, 0° azimuth represented frontal conversation. Receivers were placed at the capsule and at reference points. Mesh resolution targeted 6–8 elements per wavelength at 8 kHz.

2.3 Materials

Material properties were represented by characteristic acoustic impedance

$$Z = \rho c,$$

where ρ is density and c is sound speed. The parameters used are listed in Table 1.

Table 1: Material properties used in simulation (Z in MRayl).

Material	ρ (kg/m^3)	c (m/s)	Z (MRayl)
Silver	10,500	3,650	38.3
Titanium	4,500	5,090	22.9
Platinum	21,450	2,680	57.5
White Gold (18K)	14,000–18,000	2,800–2,940	39.2–52.8

3 Results and Discussion

3.1 Material Behavior

All metals are highly mismatched to air ($Z_{\text{air}} \approx 415$ Rayl), so geometry dominates transmission. Within that constraint, simulations revealed characteristic tendencies: silver yielded balanced response; titanium produced smoother transmission and reduced phase irregularities near 2–4 kHz; platinum generated stronger boundary reflections and narrower effective collection; white gold spanned intermediate behaviors depending on alloy, suggesting tunability.

3.2 Frequency Trends

Divergence was minimal below 2 kHz where λ is large relative to features. Above 2 kHz, differences grew as wavelengths approached channel scales ($\lambda < 17$ cm), with response variations up to ~3 dB.

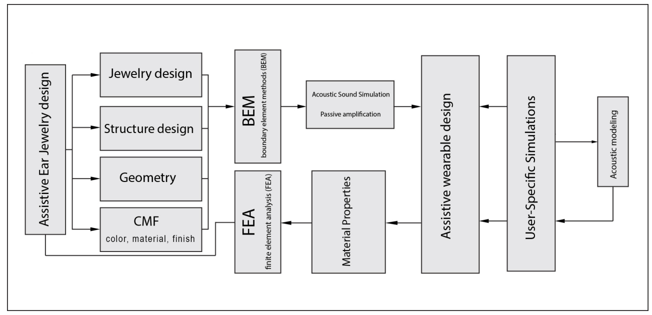

Figure 3: Workflow: geometry and material parameters → wave/BEM analysis → SPL maps and frequency responses for design feedback.

3.3 Implications

Designers could leverage material choice: silver/titanium for clarity, platinum for directional emphasis, white gold for customization. These insights extend beyond aesthetics, offering a rational basis for material selection in jewelry-scale assistance.

3.4 Limitations

Simulations omit head and pinna effects and boundary-layer physics at millimeter scales. Treble's solvers are not specialized for such small structures, so results are indicative rather than predictive. Validation with FEM and vibrometry, along with psychoacoustic testing, is future work.

4 Conclusion

Material-aware acoustic simulation provides a new design-space lens for assistive jewelry. Though effects are subtle compared to traditional hearing aids, they are systematic and actionable at early stages. Future directions include refined solvers, mixed-material modeling, and psychoacoustic validation. The Green Voice ear cuff illustrates that assistive technology can be designed not only to function but to be worn proudly.

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Plumes and Pixels: Bridging Digital and Traditional Art in SciArt Education

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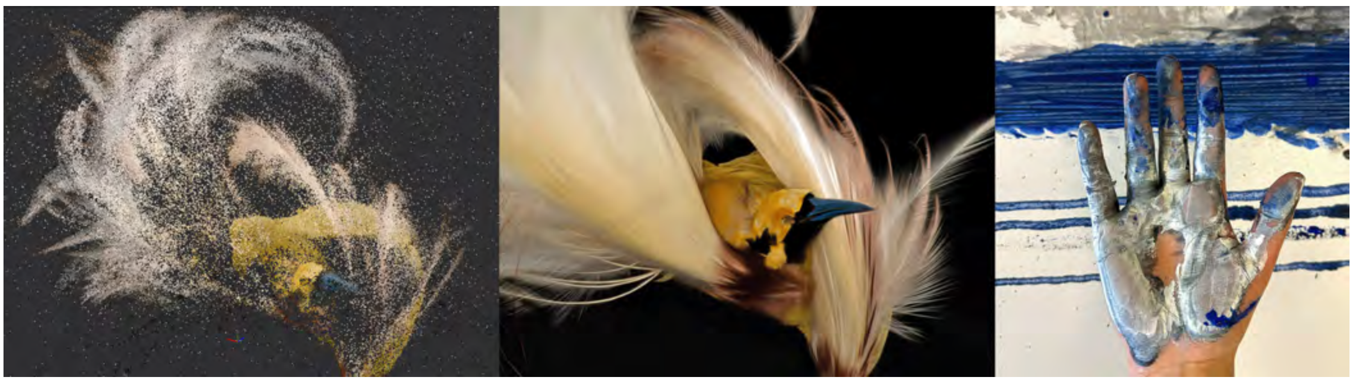

Figure 1: Producing the digital twin using 3D Gaussian Splat and making art by hand.

Abstract

This paper presents the innovative "Plumes and Pixels" project, which employs 3D Gaussian Splatting to create an interactive digital twin of a vintage bird of paradise headwear. This cutting-edge technique, particularly effective for challenging subjects like feathers, demonstrates the project's potential as a powerful teaching tool in SciArt, bridging digital techniques, natural sciences, and artistic expression. The approach uniquely reverses the traditional inspiration flow between digital and traditional art, with students producing non-digital artworks inspired by advanced digital processes and scientific concepts. This oscillation between digital and physical realms encourages exploration beyond pixels, fostering renewed appreciation for materiality and scientific observation. The process cultivates a mental creativity cycle where insights from traditional techniques inform students' digital practice. Curriculum modules leverage this SciArt-inspired digital-to-traditional art cycle, examining challenges and opportunities of integrating advanced technological projects within artistic education. The paper highlights impacts on student engagement and learning outcomes across scientific and artistic domains. By sharing these experiences, including a successful art exhibition of students' traditionally created works, we aim to inspire a shift in SciArt and digital media education. The approach demonstrates how synergy between scientific inquiry, digital innovation, and traditional craftsmanship leads to holistic learning experiences, advocating for an educational philosophy transcending the science-art dichotomy.

CCS Concepts

• **Applied computing** → **Fine arts**; *Education*; • **Human-centered computing** → *Visualization.*

Keywords

3D Gaussian Splatting, Digital Twin, SciArt Education, Interdisciplinary Learning, Digital-to-Traditional Art, Interactive Visualization, Natural Science Specimens, Computational Photography, Art-Science Integration, Creative Pedagogy

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1 Introduction

The intersection of science and art, often termed SciArt, represents a fertile ground for innovative educational approaches. As digital technologies continue to reshape both scientific inquiry and artistic expression, there is a growing need for educational methodologies that bridge these seemingly disparate domains. The "Plumes and Pixels" project emerges as a response to this need, offering a unique approach to integrating cutting-edge digital techniques and traditional art forms within the context of scientific exploration.

At the heart of this project lies a vintage headwear adorned with a bird of paradise, a relic from an era when the demand for exotic plumage in fashion led to significant ecological consequences. This artifact serves as both a scientific specimen and a cultural touchstone, providing a rich foundation for interdisciplinary study. The project employs 3D Gaussian Splatting (3DGS), a state-of-the-art technique in computer graphics, to create an interactive digital twin of this specimen. 3DGS represents a significant advancement in 3D digitization, particularly well-suited for capturing complex, organic forms like feathers, which have traditionally posed challenges for conventional 3D scanning methods.

The use of 3DGS in this context not only pushes the boundaries of digital preservation but also serves as a powerful educational tool. It allows students to engage with a high-fidelity digital representation that preserves the intricate details of the specimen, from the overall structure to the subtle textures of individual feathers. This advanced digitization technique forms the foundation for a novel educational approach that reverses the typical flow of inspiration between digital and traditional art.

The primary aim of "Plumes and Pixels" is to cultivate a new generation of students who can fluently navigate the interplay between cutting-edge digital technologies and traditional art forms, all while engaging deeply with scientific concepts. This approach addresses a significant gap in current educational practices, where digital and traditional art techniques are often taught in isolation, and where the integration of advanced computational methods into art education remains limited.

Moreover, the project introduces a novel reversal in the typical flow of inspiration between digital and traditional art. Instead of using traditional art as a starting point for digital creations, students are challenged to produce non-digital artworks inspired by the 3DGS-generated digital twin and the scientific observations it facilitates. This reversal encourages students to think critically about the relationship between digital and physical realms, fostering a deeper appreciation for both.

By oscillating between high-tech digital processes, exemplified by 3DGS, and hands-on traditional art techniques, "Plumes and Pixels" pushes students beyond the confines of pixel-based thinking. It rekindles an appreciation for materiality and direct observation, skills that are increasingly valuable in an age dominated by digital interfaces. This approach not only enhances students' technical abilities but also nurtures their capacity for holistic thinking, preparing them for the complex, interdisciplinary challenges.

We will explore the methodology behind the creation of the 3DGS digital twin, examine the curriculum modules designed to facilitate the digital-to-traditional art cycle, and analyze the project's impact on student engagement and learning outcomes. Through this exploration, we aim to contribute to the ongoing dialogue about the future of SciArt education.

Figure 2: Historical context of bird of paradise hats. Top: Woman wearing a hat adorned with bird of paradise feathers (Source: [BBC History Magazine [n. d.]]). Bottom left: Advertisement for The Parisian Hat Co. from the London Saturday Review, 1864 (Source: [Patchett [n. d.]]). Bottom right: Eaton's Catalogue Page from 1911 (Source: [Dr Merle Patchett [n. d.]]).

2 Methodology

2.1 Creation of the Digital Twin

The digitization of the vintage bird of paradise headwear specimen from the Academy of Natural Sciences' collection formed the cornerstone of this project. The process employed an advanced combination of computational photography techniques, primarily utilizing cross-polarized photography and 3D Gaussian Splatting (3DGS) to capture and recreate the intricate details of this complex specimen.

The data acquisition phase utilized a sophisticated Single Camera Multi-Light (SCML) setup, incorporating cross-polarization techniques. This system was designed to capture high-resolution, polarized and unpolarized images, with even lighting allowing for detailed surface analysis. The hardware setup consisted of a Sony A7R IV camera with a Sony GM f1.4 24mm lens, operated at f16, 1/125s, and 100 ISO, fitted with a HOYA HD3 Circular HRT Polarizer. Lighting was provided by four Godox DP600IIIV Studio Flashes with softboxes, each fitted with linear polarization filters.

Figure 3: Various angles of the bird of paradise headwear specimen from the Academy of Natural Sciences of Drexel University. Photos were taken by the authors as part of the project. The specimen is part of the Academy's collection.

This cross-polarization method was crucial in mitigating unwanted specular reflections and enhancing the capture of fine details like delicate barbules and barbs. The setup allowed for the capture of both diffuse reflectance and, when needed, specular information from the specimen's surface.

The acquisition process was highly automated, utilizing a custom Python script that integrated various libraries for wireless turntable control and camera operation. The specimen was photographed from multiple angles, with the process repeated at various camera elevations to ensure comprehensive coverage.

The integration of these datasets was achieved through 3D Gaussian Splatting, a cutting-edge technique particularly well-suited for representing complex, organic forms. 3DGS allowed for the creation of a high-fidelity, point-based 3D model that preserved both the intricate structures and the subtle color variations of the specimen. This method proved especially effective in capturing the complex interplay of different feather types, as well as preserving the localized iridescent effect found in certain feathers.

The 3DGS process involved training on the acquired image dataset, optimizing the position, size, and appearance of hundreds of thousands of 3D Gaussians to best represent the specimen. This computationally intensive process was carried out using specialized software and high-performance GPU hardware.

The resulting digital twin underwent several iterations of refinement, balancing scientific accuracy with computational efficiency and visual aesthetics. Particular attention was paid to preserving the iridescent qualities of certain feathers, which required innovative solutions in the 3DGS training process. The final model was optimized for interactive display, allowing users to examine the specimen from multiple angles and zoom levels, providing an unprecedented level of detail and interactivity.

This advanced digitization process not only resulted in a highly accurate digital representation of the specimen but also served as a rich source of inspiration and study for the subsequent artistic and educational components of the project.

2.2 Theoretical Framework

The "Plumes and Pixels" project is underpinned by a theoretical framework that draws on the concepts of heteromorphic imagination and phenomenological gestures, as discussed by Polyak and Balkhyoor [Polyak and Balkhyoor 2024]. These ideas provide a foundation for understanding the creative processes involved in translating digital experiences into traditional artworks and inform the project's unique approach to SciArt education.

Heteromorphic imagination, as defined in previous research, refers to a state of mental fluidity where mental associations and episodic memories intermingle freely to generate novel possibilities. In the context of this project, heteromorphic imagination is cultivated as students engage with the 3D Gaussian Splatting (3DGS) digital twin. The highly detailed and interactive nature of the 3DGS model encourages students to explore the specimen from multiple perspectives, fostering a state of unconstrained, radically divergent thought that spans real and speculative interpretations of the object.

Complementing this concept are phenomenological gestures, understood as pivotal events in the creative process where one mode of thinking transmutes into another. In "Plumes and Pixels," these gestures manifest as the moments when students transition from digital exploration to traditional artistic creation. These are significant metamorphic events where the fluid, exploratory engagement with the digital twin crystallizes into compelling, constructible ideas for physical artworks.

This theoretical foundation supports the project's unique reversal of the typical inspiration flow between digital and traditional art. By using the advanced 3DGS digital twin as a starting point for traditional artistic creation, the project aims to induce a state of heteromorphic imagination, facilitating novel connections between scientific observation, digital technology, and artistic expression.

The oscillation between digital and physical realms, central to the project's methodology, is theorized to enhance this process. As students move between the detailed digital representation and the tactile experience of traditional art-making, they encounter multiple opportunities for phenomenological gestures. These moments of transition become critical points for creative insight and interdisciplinary connection.

2.3 Curriculum Design

Building upon the theoretical framework of heteromorphic imagination and phenomenological gestures, a series of curriculum modules were developed to guide students through the digital-to-traditional art cycle.

The curriculum was structured into four main modules:

(1) **Introduction to Advanced Digital Techniques:**
This module familiarized students with the 3D Gaussian Splatting (3DGS) technique used to create the digital twin.

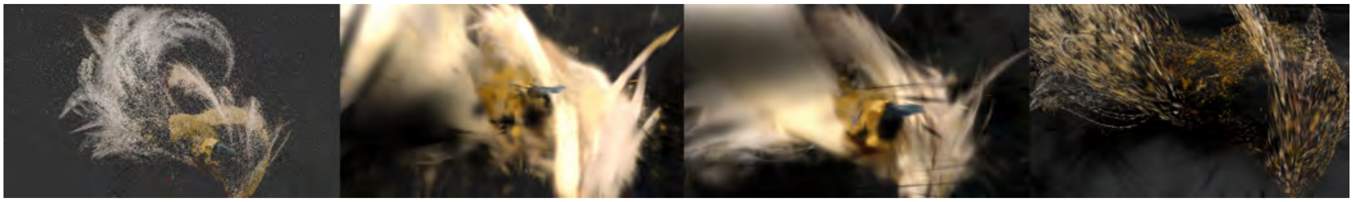

Figure 4: Various stages of the 3D Gaussian Splat training process. The real-time nature of the rendering reveals dynamic patterns and structures, appearing artistically constructive and inspiring.

Students learned about the principles of computational photography, cross-polarization methods, and the advantages of 3DGS for capturing complex, organic forms. Hands-on sessions allowed students to interact with the digital twin, understanding its construction and the level of detail it preserves.

(2) **Scientific Observation and Digital Interaction:** Students engaged in detailed study sessions with the interactive digital twin. They were encouraged to examine the specimen from various angles and scales, paying particular attention to the intricate structures of feathers, color variations, and the iridescent qualities captured by the 3DGS model. This deep engagement was designed to induce states of heteromorphic imagination, where students could freely associate scientific facts with visual observations.

(3) **Digital-to-Traditional Translation:** In this pivotal module, students were challenged to create traditional artworks inspired by their digital experiences. The focus was on identifying and leveraging phenomenological gestures as students transitioned from digital to physical media. Students were encouraged to experiment with various traditional art forms, from painting and sculpture to textile work, translating their digital observations into tangible creations. This process was designed to make explicit the moments of creative insight that occur during the transition between digital and physical realms.

(4) **Reflective Practice and Interdisciplinary Synthesis:** The final module focused on reflection and synthesis in the form of public talks. Students were encouraged to articulate their creative processes, identifying moments of heteromorphic imagination and discussing how insights from traditional techniques informed their understanding of digital processes. This reflective practice aimed to consolidate learning and foster metacognitive skills. Students also explored how their projects connected to broader themes in ecology, fashion history, and digital preservation, emphasizing the interdisciplinary nature of their work.

Students were encouraged to make unexpected connections, challenge conventional boundaries between disciplines, and reflect deeply on their creative processes. The curriculum was implemented over a two-term long course, allowing ample time for students to engage deeply with both digital and traditional techniques.

The course culminated in an art exhibition where students showcased their traditionally-created works. This exhibition served not only as a demonstration of student achievements but also as a platform for engaging the broader community in discussions about the intersection of technology, art, and science.

Figure 5: Final 3D Gaussian Splat model, showcasing the intricate details and realistic rendering of the bird of paradise headwear.

3 Results

The "Plumes and Pixels" project yielded rich qualitative outcomes, showcasing the depth of engagement and learning experienced by the PhD and master's students involved. The project's experimental nature, particularly in the application of 3D Gaussian Splatting (3DGS), provided students with unique opportunities for discovery and learning.

3.1 Interdisciplinary Learning and Collaboration

Students demonstrated significant growth in their understanding of both cutting-edge and established technologies. While 3DGS offered a frontier for exploration and innovation, students also gained proficiency in the well-established field of computational photography. The project fostered a collaborative environment where students worked both independently and in teams, mirroring real-world research scenarios and enhancing their ability to navigate complex projects.

3.2 Public Engagement and Communication

A key outcome of the project was the students' engagement with the public through an art exhibition and community talks. This experience provided valuable opportunities for students to communicate complex scientific and artistic concepts to diverse audiences, honing their skills in public outreach and science communication.

The exhibition, featuring artworks and collections developed by the students, served as a tangible demonstration of their ability to translate digital experiences into traditional art forms. This translation process embodied the concepts of heteromorphic imagination and phenomenological gestures, as evidenced by the diverse and innovative artworks produced.

3.3 Interdisciplinary Connections and Historical Context

The project's success was significantly enhanced by its truly interdisciplinary nature, bridging natural sciences, digital technology, art, and fashion history. This interdisciplinary approach was embodied in the collaboration between the project's co-authors, combining expertise in digital media and fashion scholarship.

The fashion history component, led by faculty, was crucial in navigating the complex historical and cultural dimensions of the specimen. Given the hybrid nature of the bird of paradise headwear—an artifact that straddles the realms of natural history and fashion design—this expertise was invaluable. Students gained deep insights into the sociocultural contexts of fashion history, the ethics of using exotic materials in design, and the evolution of attitudes toward wildlife conservation in the fashion industry.

Students' interactions with scientists and museum experts from the Academy of Natural Sciences complemented this fashion-oriented perspective, deepening their understanding of ecological and scientific aspects related to the specimen. These connections allowed students to contextualize their work within broader scientific and conservation efforts.

The integration of fashion scholarship and scientific expertise enriched the students' research process as they investigated the origins of the specimen. By connecting with various historical societies, searching fashion archives, and analyzing period-specific design trends, students were able to trace the provenance of the hat and situate it within broader narratives of fashion history and cultural change. This multifaceted approach to historical research added a rich dimension to their scientific and artistic explorations, enabling students to craft more nuanced and historically informed artistic interpretations.

This blend of scientific rigor, technological innovation, artistic creativity, and fashion historical context exemplifies the project's success in fostering a holistic understanding of the specimen. It demonstrates how interdisciplinary collaboration can yield insights that go beyond what any single field could provide, preparing students for the complex, interconnected challenges of modern research and creative practice.

3.4 Artistic Outcomes

3.5 Innovative Approaches and Recognition

The Academy of Natural Sciences rated the work extremely highly, noting that it pointed to a unique and completely new direction in specimen digitization and public engagement. This recognition underscores the project's success in bridging traditional museum practices with cutting-edge digital techniques and artistic interpretation.

The project culminated in a diverse array of individual artworks, each demonstrating a unique engagement with the concepts of heteromorphic imagination and phenomenological gestures. These pieces showcased the students' ability to translate their digital experiences and scientific understanding into tangible, emotive art forms:

Figure 6: Arefeh Ahmadi giving a talk about her work at the exhibition.

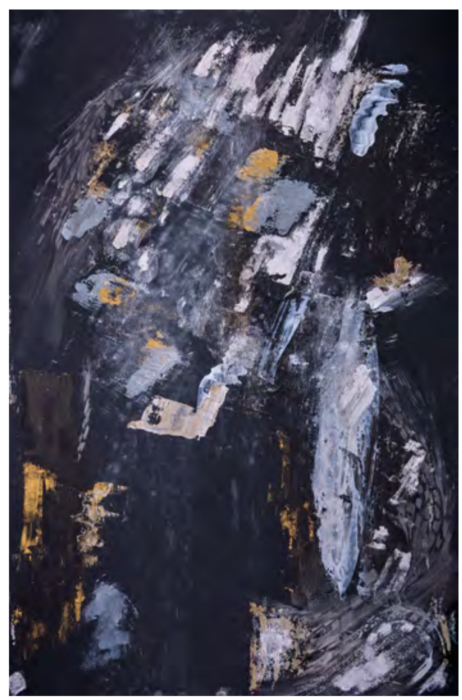

Figure 7: Arefeh Ahmadi's "Arsenic- king of Poisons AS 33 – 74.92."

Arefeh Ahmadi's collection in the "Unseen Shadows" series explores themes of preservation and the complex relationship between life, death, and artistic representation. Ahmadi's works are

Figure 8: Arefeh Ahmadi's "Fall."

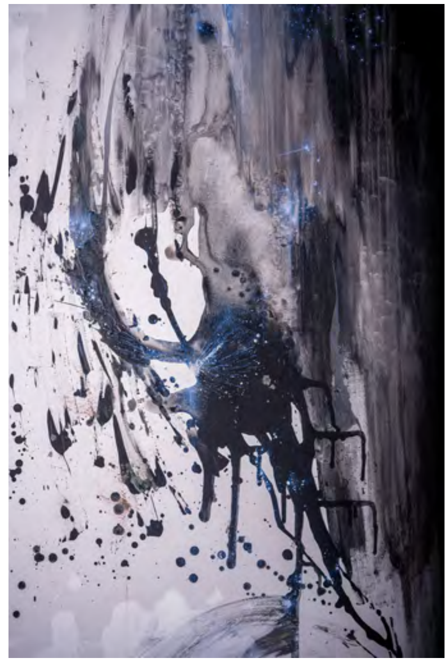

Figure 9: Arefeh Ahmadi's "ACT 2 - Captive Bird."

deeply inspired by scientific processes, particularly the use of arsenic in the preservation of specimens, which she interprets both literally and metaphorically.

In *"Arsenic - King of Poisons"*, Ahmadi delves into the paradox of preservation through the chemical structure of arsenic and its natural form. This artwork bridges scientific knowledge with artistic interpretation, reflecting on the tension between decay and timelessness. Her intricate representation of arsenic in both its lethal and preservative roles adds depth to the dialogue between life and death.

"Fall" depicts a bird sinking into the earth, its wings stretched in a desperate attempt to escape. The use of earthy colors and textured brushstrokes effectively conveys the sense of entrapment, reflecting the fragility of freedom and the consequences of human actions on nature. The imagery evokes a strong emotional response, illustrating both the beauty and tragedy of the bird's plight.

In *"ACT 2 - Captive Bird"*, Ahmadi explores the relationship between light and shadow. The piece engages viewers with stark contrasts, drawing upon da Vinci's observations about shadow as a necessary counterpart to light. The composition is centered around a bird in captivity, its outline blurred in the surrounding darkness, symbolizing the struggle between confinement and the desire for liberation.

Ahmadi's collection reflects her fascination with the intersections of scientific history, natural beauty, and the emotional depth found in moments of captivity and release. Each work invites viewers to ponder the delicate balance between destruction and preservation, highlighting how art can illuminate scientific themes in a deeply emotive manner.

Rghad Balkhyoor's "Threads of Nature" and "Paradise Plundered", part of the Woven Narratives Collection, employed Nuno

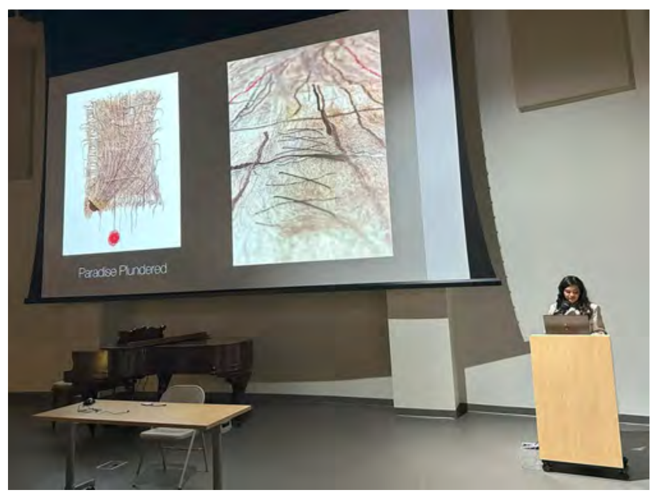

Figure 10: Rghad Balkhyoor presenting her work at the exhibition.

felting to create textural narratives. "Threads of Nature" used striking red threads to symbolize human desire against a backdrop of earthy tones, while "Paradise Plundered" incorporated muted grays and thin red lines to evoke the complex history of bird preservation and exploitation.

Balkhyoor's deep connection with material-based design was instrumental in shaping her contributions to the project. Drawing parallels between the delicate textures of the bird's feathers and the tactile process of Nuno felting, Balkhyoor translated her research

Figure 11: Rghad Balkhyoor's "Threads of Nature."

into the "Woven Narratives" collection. Her works, "Threads of Nature" and "Paradise Plundered," not only reflect the beauty of nature but also confront the historical exploitation of the Birds of Paradise. In her pieces, bold red lines serve as a metaphor for human greed and its impact on ecosystems, while intricate stitching signifies nature's resilience. Through her work, Balkhyoor invites viewers to reflect on the fragility of natural habitats and the necessity of conservation efforts.

Darren Woodland, Jr.'s digital prints in the Feathered Futurism and Digital Dreams Collection showcased a unique blend of historical aesthetics and contemporary digital techniques. "The Aviator" fused Art Deco design with 3D geometric complexity, while "Canopy" paid homage to Art Nouveau's flowing lines. "Flight of the Navigator" imaginatively combined avian elements with retro-futuristic mechanical components. Each of these works demonstrates the artist's individual journey through the digital-to-traditional art cycle, reflecting his unique interpretations of the specimen's scientific, historical, and cultural significance. Woodland's deep dive into design trends and popular culture of the early 20th century is evident in his reinterpretation of these visual motifs. His work captures not only the allure and status of fashion during that period but also the symbolic power the bird of paradise held as a representation of luxury and aspiration.

By bridging the past and present, Woodland prompts a reconsideration of the ethical implications tied to such beauty, blending historical reverence with modern critique.

Figure 12: Rghad Balkhyoor's "Paradise Plundered."

Figure 13: Darren Woodland, Jr. discussing his artwork at the exhibition.

Figure 14: Darren Woodland, Jr.'s "Flight of the Navigator."

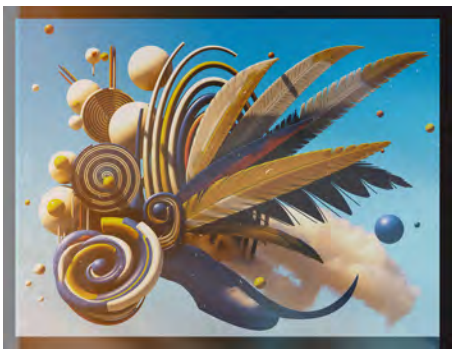

Figure 15: Darren Woodland, Jr.'s "The Aviator."

Figure 16: Darren Woodland, Jr.'s "Canopy."

4 Conclusion

The "Plumes and Pixels" project demonstrates the potential of innovative pedagogical approaches. By leveraging advanced digital techniques like 3D Gaussian Splatting as a springboard for traditional creative expression, this initiative has opened new avenues for learning and discovery.

Key outcomes of this project include:

(1) Enhanced student engagement through hands-on experience with cutting-edge visualization methods.
(2) Successful translation of complex digital experiences into tangible, emotive artworks.
(3) Deepened understanding of historical artifacts through a multifaceted lens, combining contemporary techniques with traditional research methods.
(4) Improved public outreach skills, as evidenced by the well-received exhibition and community talks.

Figure 17: Art Exhibition at Kennett Library.

The project's success in connecting diverse fields offers valuable insights for curriculum development in higher education. It demonstrates how seemingly unrelated disciplines can be interwoven to create rich, meaningful learning experiences. This approach prepares students for the nuanced challenges of modern professional environments, where critical thinking and unique perspectives are increasingly valued. By fostering these skills, the project equips students to navigate and contribute to complex, multifaceted domains.

In conclusion, this project not only achieved its educational goals but also pointed towards a new paradigm in teaching – one that embraces complexity, encourages cross-pollination of ideas, and prepares students to be versatile, creative problem-solvers.

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Homeostasis

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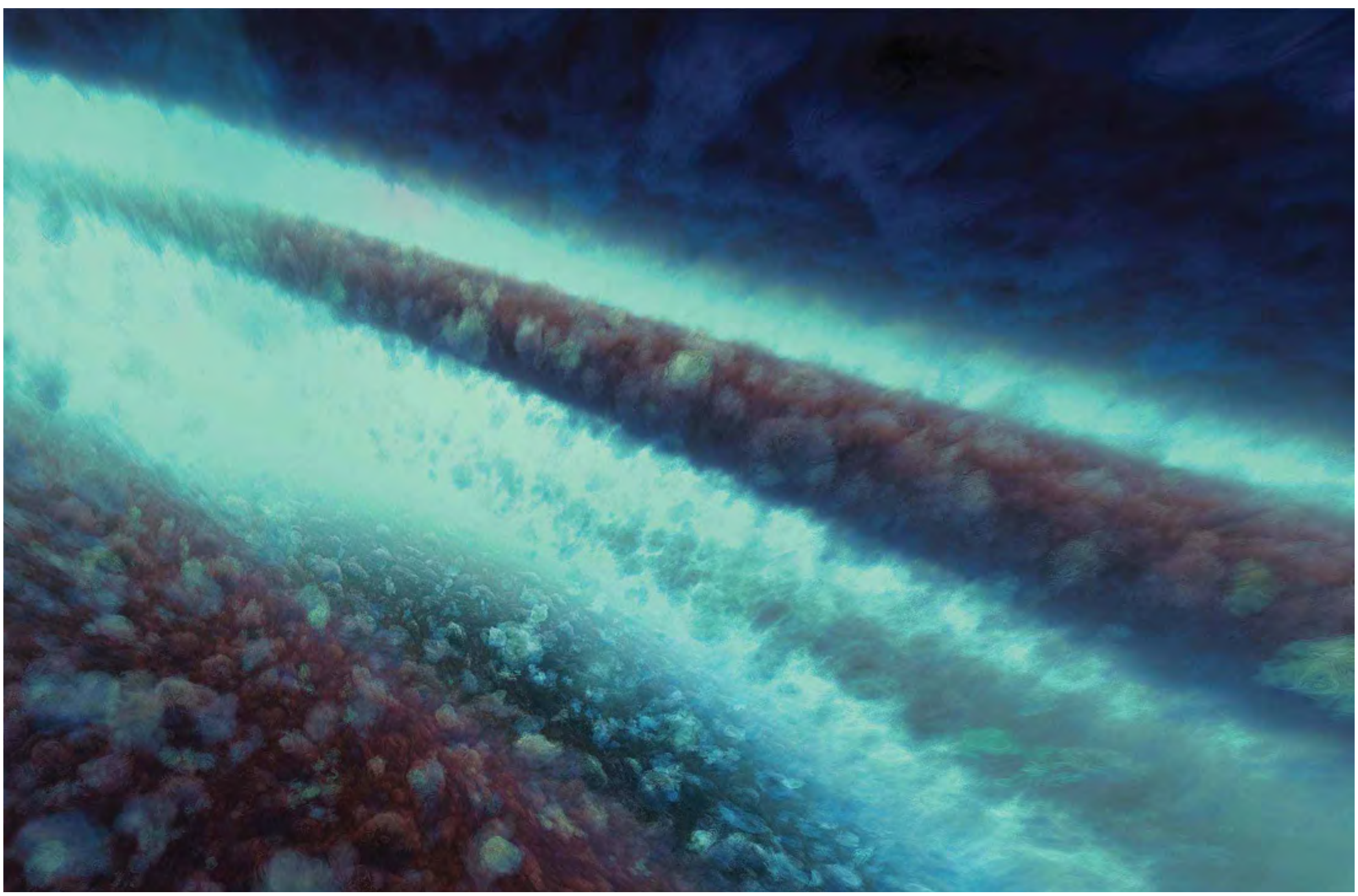
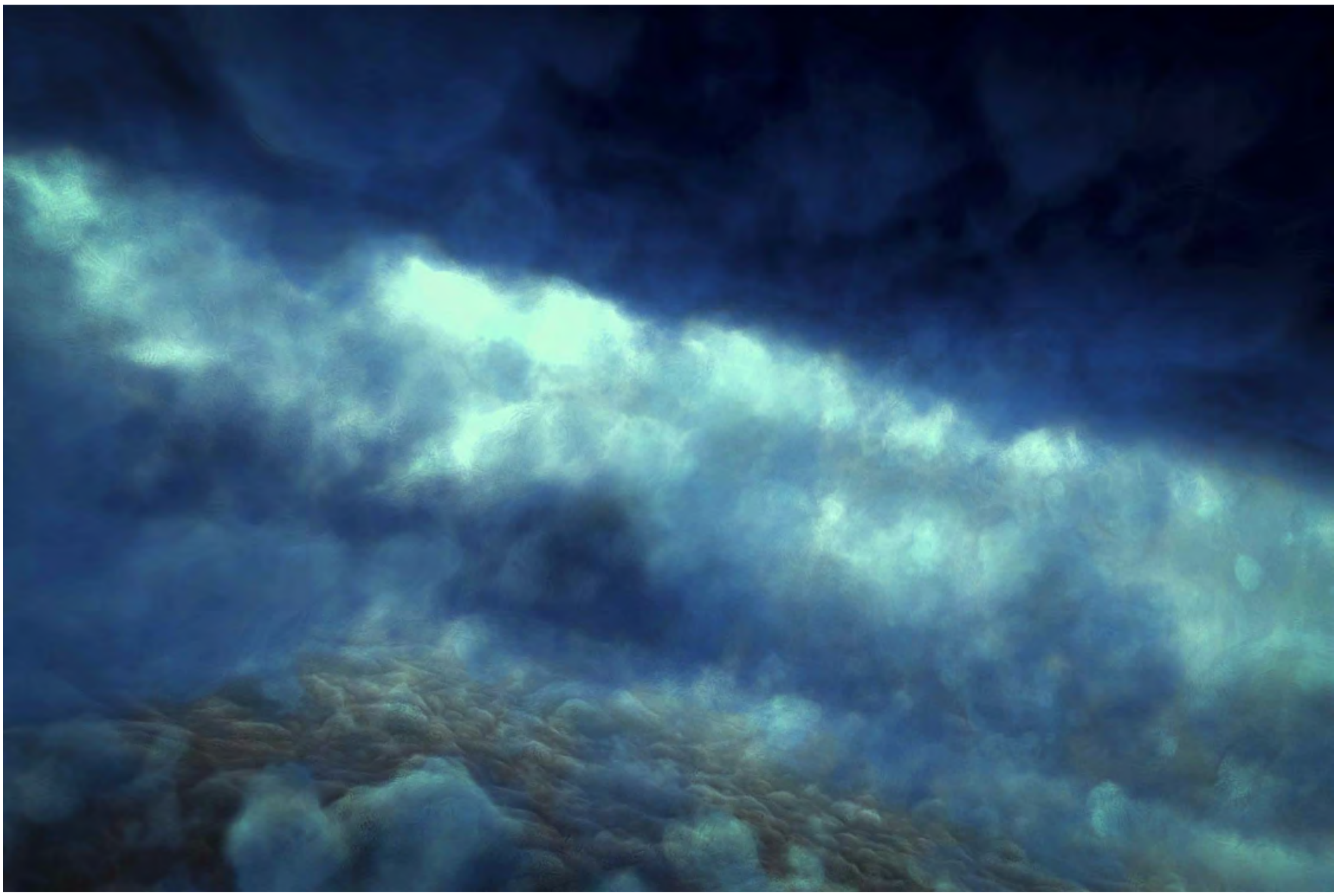
www.polyzaar.com

Emerging technologies are impacting human interactions more than ever, while public perception of automation, artificial intelligence (AI) and human enhancement remains critical. In creative fields, innovative ideas are often triggered by intersecting dissimilar phenomena filtered through aesthetic considerations. One can argue that introducing AI in artistic practice destroys spontaneity, intuition and serendipity; consequently, the outcome is deliberate and premeditated. However, art is open to interpretations and through designing of unorthodox digital artifacts, interfaces and experiences in contrast with mainstream processes, we can challenge existing beliefs and provoke new ideas to reach a better understanding of how technology affects our culture. The project *Homeostasis* is a speculative interactive visual experience. It connects a distinctive interface design with generative art and meaningful data to communicate a significant topic. Shapes, colors, form and timing are manipulated based on a set of design principles, while the pattern of a vapor cloud from an ultrasonic vaporizer is analyzed and processed in a machine learning model in real time. The variations of the vapor pattern enable infinite possibilities between the natural boundaries and provide exciting data through computer vision that then drives the spatial and temporal attributes of the animation. The design is biologically inspired, and it attempts to create an illusion of cellular life-forms in deep waters.



Homeostasis

Emil Polyak



Homeostasis

Emil Polyak

Homeostasis

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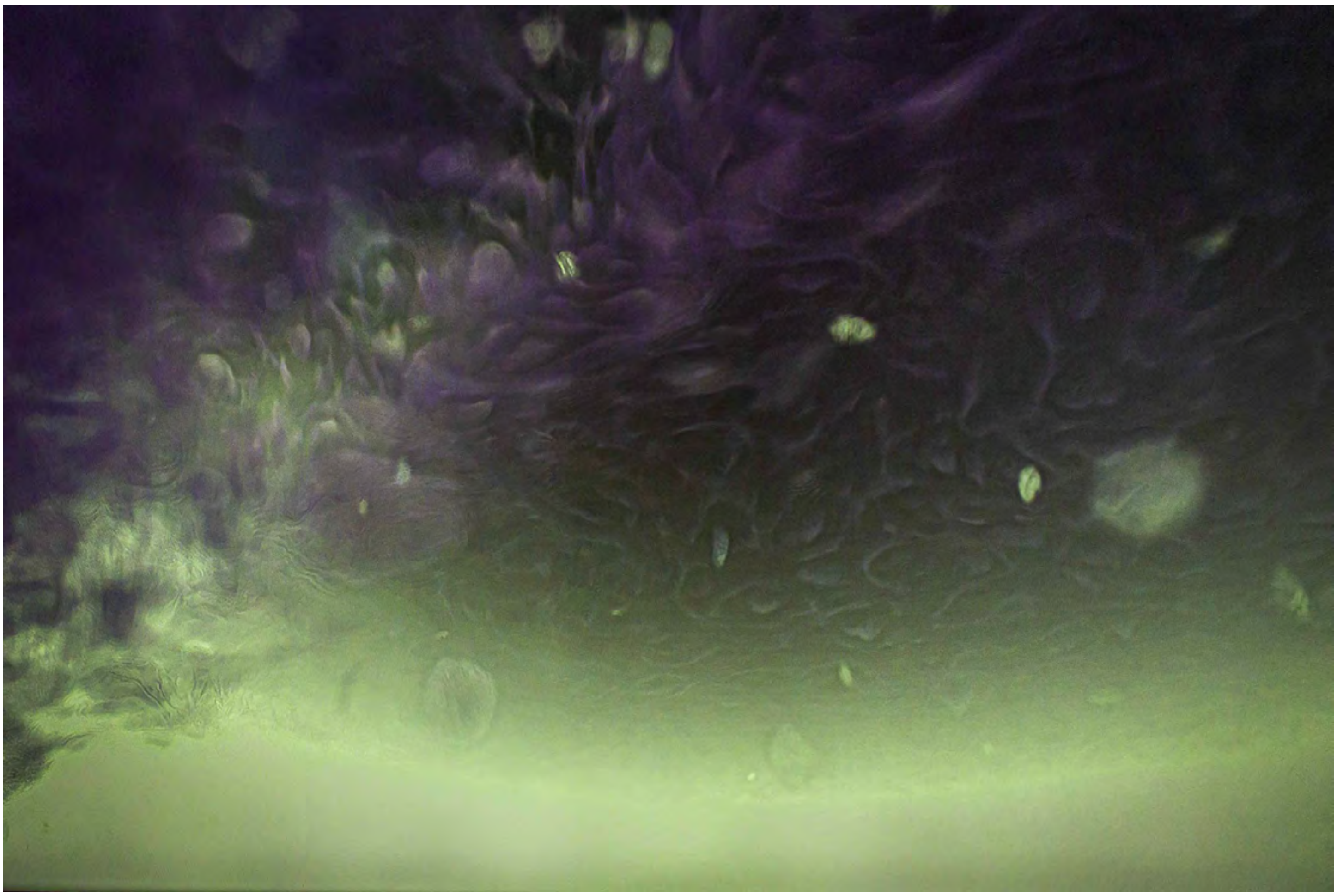
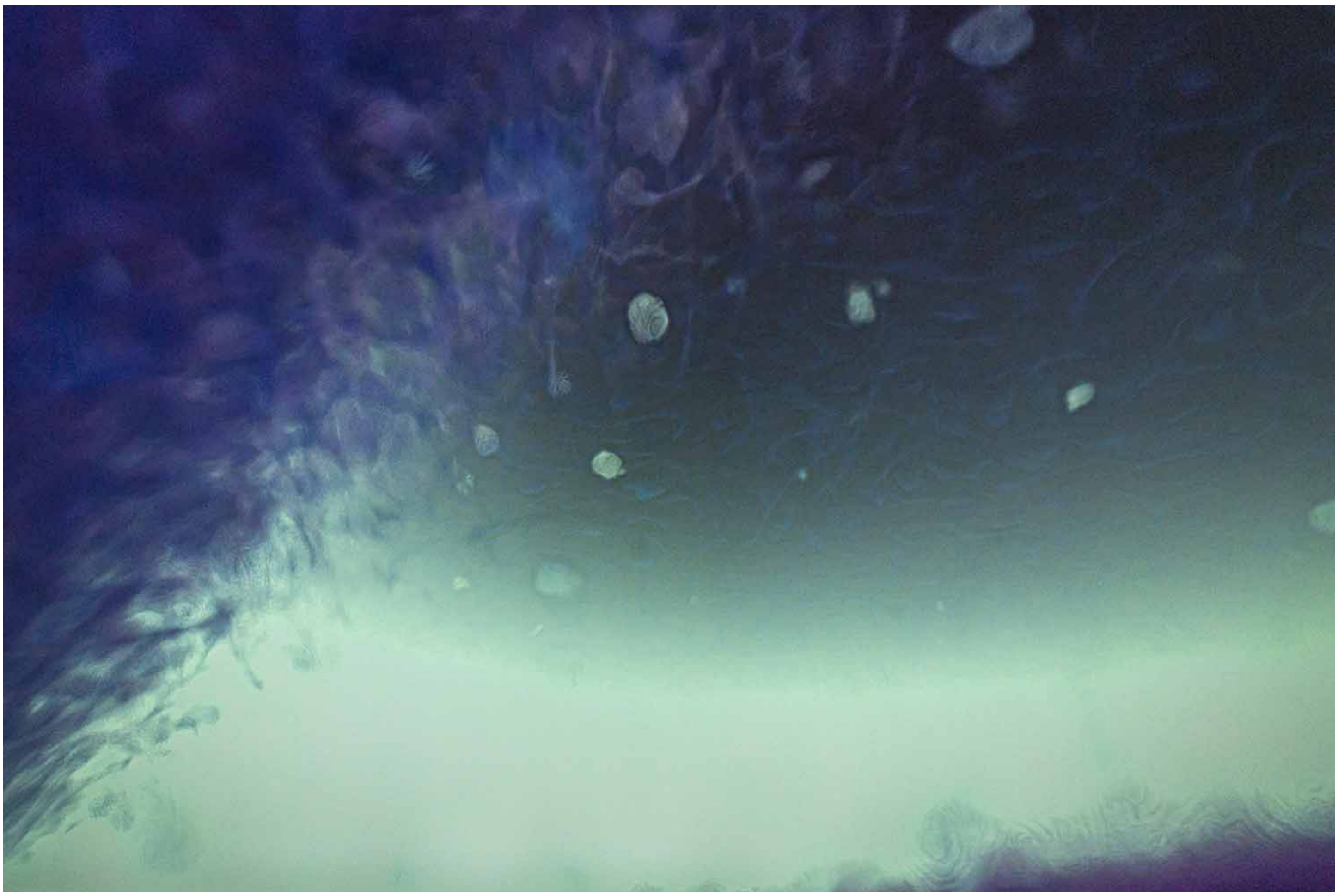


Homeostasis

Emil Polyak

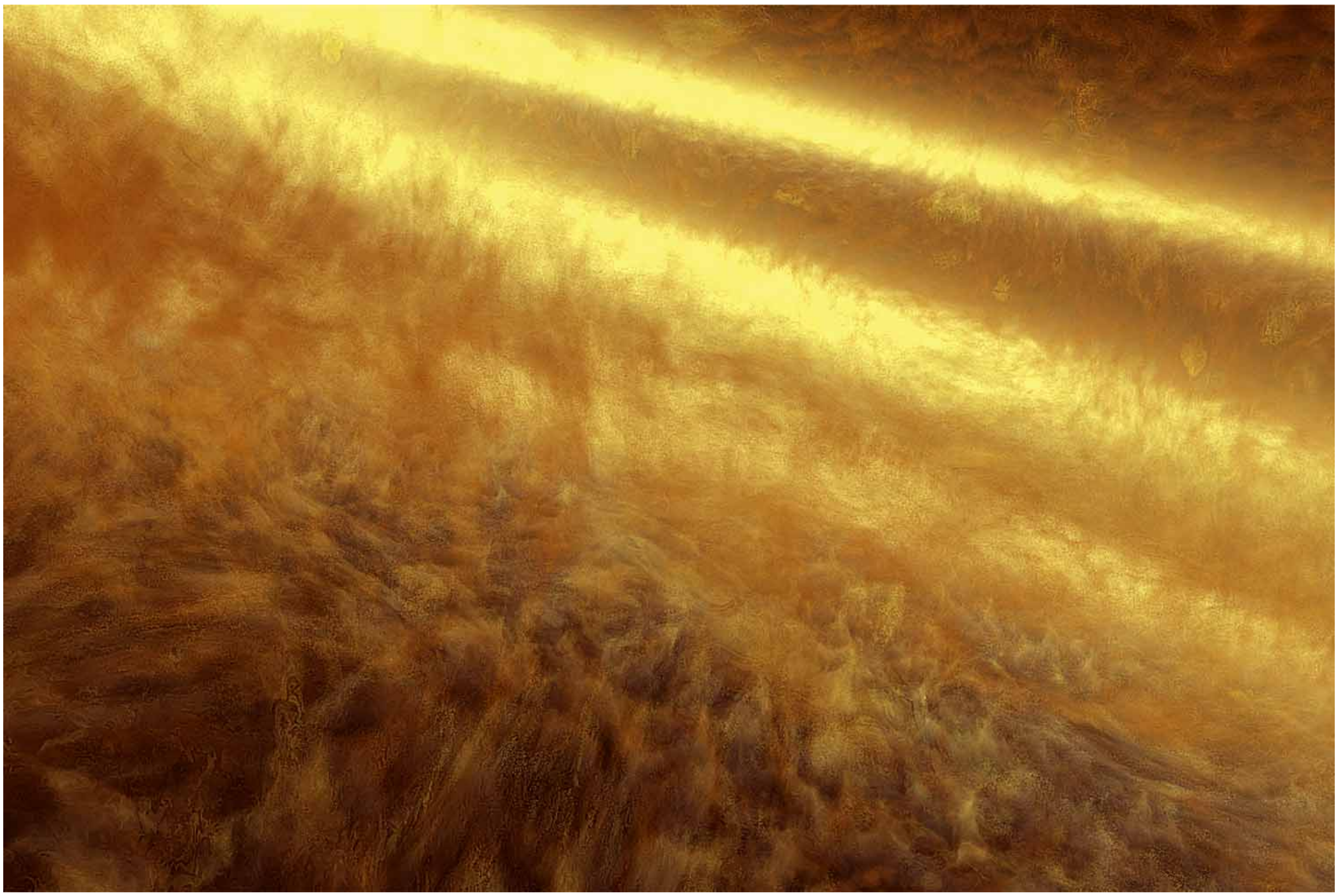


Homeostasis

Emil Polyak

Homeostasis

Emil Polyak



‘Homeostasis’ and Human Interference

by SIGGRAPH Conferences

We value our storytellers, praising writers, directors, and poets. But, receiving no recognition or acknowledgement is perhaps the greatest storyteller of our generation: data. Emil Polyak emphasizes the importance of this powerful narrator, highlighting the human impact on climate change, in his SIGGRAPH 2020 Art Gallery selection, “Homeostasis”. We caught up with Emil to better understand his process for developing generative art, working with a multidimensional dataset, and creating interactive elements.

SIGGRAPH: Talk a bit about the process for developing your project, “Homeostasis.” What inspired you to pursue this concept in your artwork?

Emil Polyak (EP): Data and information consumption has always been a great interest of mine, especially how factual, quantitative, and scientific data today is still subjected to societal disapproval and, many times, distortion. Despite vast efforts to demystify science, the public perception of data hangs on pseudoscientific viewpoints and context, prone to political influence, that are filtered through bizarre ideologies from time to time, or simply sugarcoated to support economic expectations.

Data related to climate change is currently looked at through this prism, despite the multiple dimensions and connections, such as greenhouse gas emission and global sea level rise. In my mind, data sets are fascinating stories; every spike and every dip is a plot point beyond the numbers. Just think of the current health crisis and how it affects all aspects of our lives each day. In a hundred years, it will only be data from the distant past, and we can only hope that the public will not see it as “fake news.” “Homeostasis” was inspired by the dissonance in how the public interprets, ignores, and denies data, and how present actions reflect back on data, consequently shaping our future. Therefore, the interactive component represents our bias and also our ability to turn things around, if we want to.

SIGGRAPH: **Let’s get technical. How did you develop this project? How many people were involved? How long did it take? What was the biggest challenge? Our audience loves details!**

EP: I started working on elements of this project about a year ago. The initial design process involved the conceptualization of what I wanted this piece to feel like. Most artists start by sketching ideas to see what works. However, for generative art, my process is more primitive because I know that, at the end of the day, I will need to develop everything procedurally, so my thinking must start that way, too.

In an attempt to imagine something that is unreal, yet familiar, I came up with a few principles, including motion derived from rotation, structural symmetry and functional asymmetry, vertical and horizontal space, segmentation and grouping, and repetition. This process helped me to find an entry point to dive deep and actually start making things appear on the screen. The next step was to consider and test variations with texture, time, shapes, dimension and form, direction, and value. With a background in animation and coding for various interactive installations, I wanted to explore shader programming (GLSL) for this project. This involved learning an almost entirely different logic compared to typical Python scripts for example, and, since I am not a computer scientist, it also meant opening some math books on functions and other special topics. I have worked with audio signal processing in the past and have always enjoyed the idea of deconstructing acoustic waves.

SIGGRAPH: Can you elaborate on the how the animated art was developed? How about the vapor cloud?

EP: From an artistic standpoint, almost any multidimensional dataset, such as those related to climate change, can be observed similarly to how sound is seen in the time domain compared to the frequency domain. It really does not make much sense for data scientists, but in artistic expression, it forces me to stay within the objective boundaries of the data while modulating the visual variables. For this purpose, my application continuously samples the data, while it also continuously changes the scope and the way of interpretations. Basic examples would be time-slice comparison, averaging, and measuring the sharpness of a spike or a dip. These samples are variables that affect shapes, colors, transitions, camera, and light.

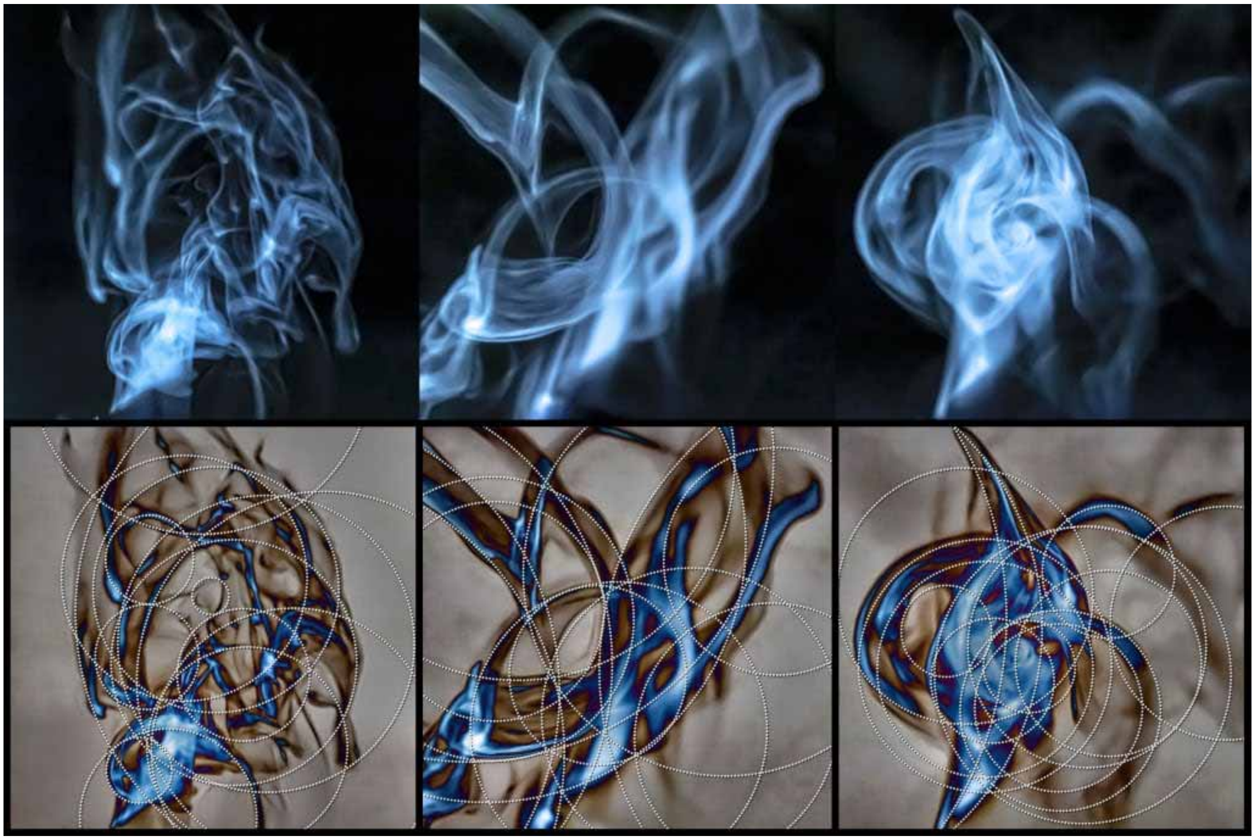
The interface is made of a moving vapor cloud that keeps projecting in the air from a small water container, while being captured by a camera and analyzed in real time inside the application. Without any interaction, the cloud movement modulates the data in its own way “naturally”. When users interact with the vapor, they affect it in ways that never happen without the interaction, and these interactions translate into bias and forceful shifts, altering the data for better or worse.

Different results with GLSL.

SIGGRAPH: **Can you walk us through, step-by-step, development of the most challenging technical aspect of the work?**

EP: The most challenging part of the work was developing the interactive component using the vapor cloud. I used a piezo-electric transducer, which is a very simple component that converts high-frequency electronic signal into high-frequency mechanical oscillation. When submerged, the water tries to keep up and follow the oscillation, but this is impossible due to mass inertia, and as the result the momentary vacuum forces extremely tiny droplets into the air. I have tested several commercially available devices, but none of them met my expectations on the visual side, so I fabricated a custom one. I have experimented with different frequencies to achieve the whispy, slow emission. I ended up with 1.72 MHz with the appropriate transducer designed for that range.

I recorded a large amount of high-resolution samples using a DSLR camera, and started analyzing them by sketching them on paper. Looking closely some reminded me of X-ray images of bones and internal organs, while others looked more like smoke. What I really liked was the twisting, ribbon-like shapes, tapering, waving, folding into circles, compressing, pinching, then spiraling back into a ribbon before disappearing entirely. These visual characteristics were directing my decisions to filter the input in ways that allowed me to train a machine-learning module to recognize and classify these changes by finding 15 circles in each frame. The position and the radius of these circles is what matters most. I am happy with the outcome, and I think it is a special area that I will be exploring more in the future with stereo vision.



Vapor cloud analysis. Breakdown to 15 circles

SIGGRAPH: **This art can really help people understand the drastic changes in sea level that our oceans have endured. What impact are you hoping to make on SIGGRAPH's global audience? What message do you want conference participants to take away?**

EP: I see artistic expression as an opportunity to tap into empathy. This interactive visual journey attempts to evoke emotions by triggering virtual flashbacks of calm ocean currents, microorganisms, large waves, and strange atmospheres, while also bringing the viewer into extensive air pollution, garbage patches, and fiery temperatures.

I think "understanding" can happen in many ways. What I am hoping is that the piece is memorable enough to generate an emotional impact and that participants will think about how they felt the next day. SIGGRAPH's audience is an amazing community of highly motivated and talented creators, tirelessly pushing boundaries. I hope that they will find it creatively inspiring and appreciate the importance of communicating serious topics to the public using computer graphics.

SIGGRAPH: **What's next for "Homeostasis"? How do you plan to continue fostering change and action?**
EP: I plan to present the project in New Mexico this Fall to a different audience, and hopefully there will be more opportunities in the future. I am currently doing research on the issue of sustainability connected to digital media and technology. Motivated by the vapor cloud, I would like to explore different interactions with natural surfaces and interfaces.

Homeostasis

Emil Polyak

Homeostasis

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Homeostasis

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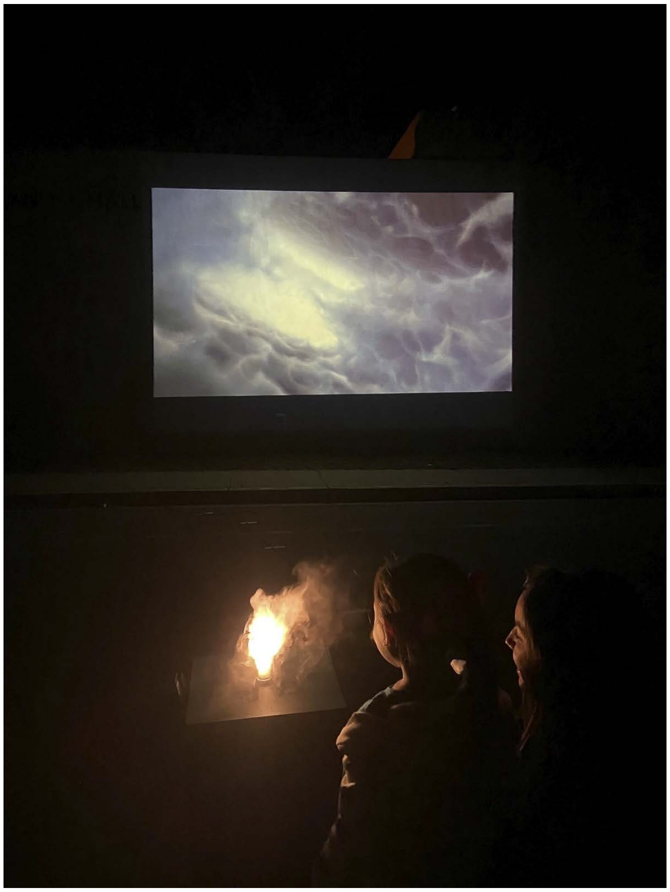
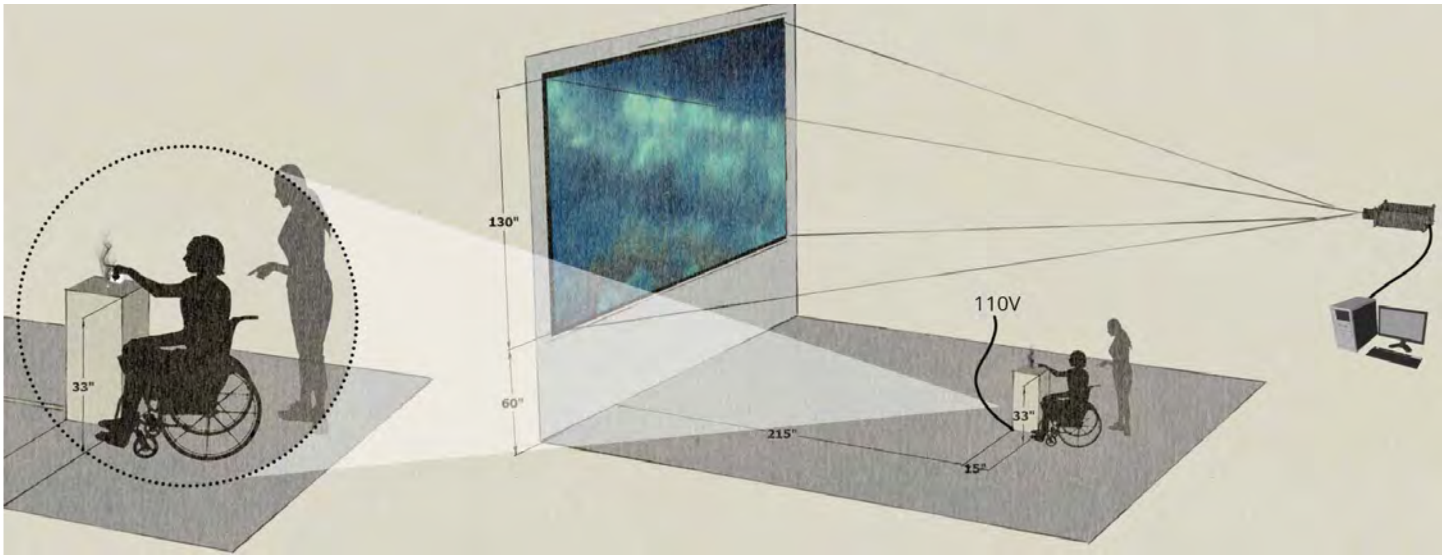


Homeostasis in Taos, New Mexico
(PASEO Festival).

Homeostasis

Emil Polyak



Homeostasis

Emil Polyak

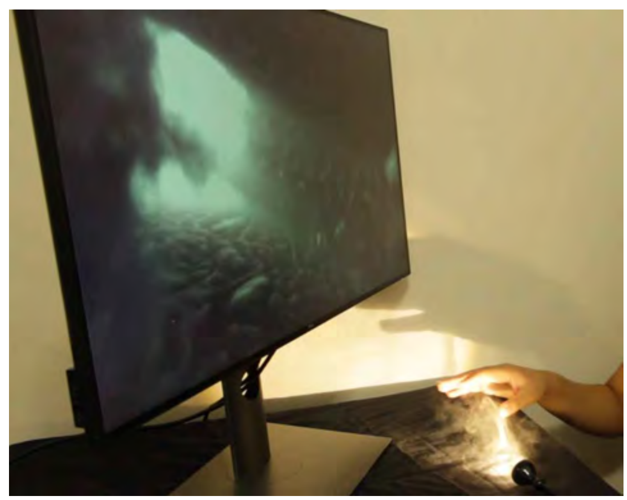
DiVA "Digital, Interactive and Visual Arts" is a Society of Art and Science academic journal in Japan that has been published since 2001.

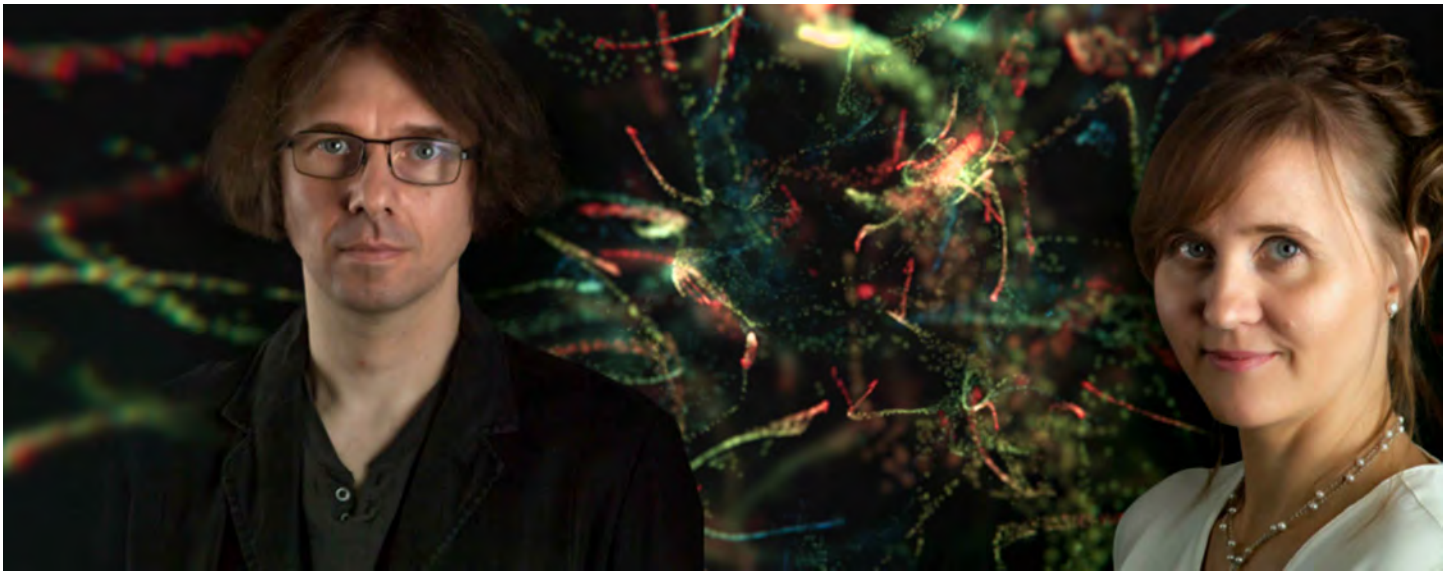
D i V A

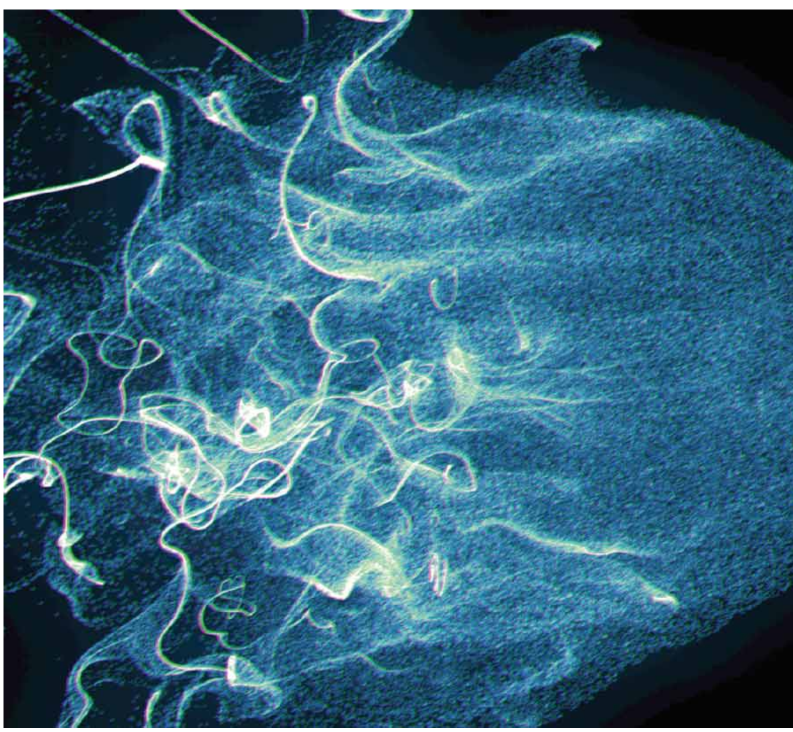
Homeostasis

Emil Polyak
Drexel University | U.S.A.
www.polyzaar.com

　作品名の「ホメオスタシス」は、生物が身体の状態を保とうとする働き、恒常性の機能であることは良く知られている。この作品では超音波で気化させて発生させた煙をユーザーが遮ったり払ったりできる。そのように形状が乱された煙をキャプチャしてコンピュータ画面に映し出している。生物のような蠢きもある。様々な生物の棲む海の営みがシミュレートされ、鑑賞者が干渉してこの営みを壊すことが出来るというメタファーだそうだ。しばらく放っておくと、自然な変化しかしない状態に戻っていく。ホメオスタシスの原理が働いているとも言える。作品の発想は、レオナルド・ダ・ヴィンチが 1517 年に描いた乱流のスケッチや大噴火を起こしたヴェスヴィオ火山などの自然現象に関する事柄から得ている。







...Our Passage to the Stars...

OLGA KLEIANKINA, PIANO
EMIL POLYAK, AI PROJECTIONS

This project conveys an imaginary human journey to the stars.

We look at the stars and dream, and our dreams compel us to brave our inventions for the perilous passage, allowing us to know the world better. As humans, we will experience the knowledge of this universe through our emotions and relative to our spiritual beliefs, superstitions, and symbols we hold dear—all of which will become part of our interaction with the cosmos.

MUSIC OF THE STARS

Live piano and real time computer animations fuel a musical journey into space

BY ERIN ZANDERS

PHOTO BY BECKY KIRKLAND

THE STARS, MOON AND PLANETS have captivated humanity since our earliest records of civilization. Bone sticks marked to track the phases of the moon were discovered in Africa and Europe and date back possibly as long ago as 35,000 BC. So it's no wonder that, as we evolved and began to express ourselves through the arts, this preoccupation with exploring and understanding the cosmos would creep into our music, paintings and writings.

Dr. Olga Kleiankina, the director of piano studies for the NC State Department of Music, interpreted this fascination with space exploration through music, visual art and dance in a piano recital originally given in February 2018 titled "...Our Passage to the Stars."

"I think exploration is one of the inciting forces that makes humanity move forward," said Kleiankina. "So many things that relate to what is human can also relate to the theme of the recital. It is our emotions, our fears, our bravery, our inventions, our breakthroughs, and simply our dreams when we gaze at the starry sky."

"...Our Passage to the Stars" incorporated a performance from the NC State Dance Program, and innovative computer-generated visuals by art and design professor Emil Polyak which were created live during the recital in response to the notes played by Kleiankina on the piano. That groundbreaking recital, which Kleiankina describes as "an imaginary human journey to the stars," was selected in September to be part of ACCelerate in Washington D.C., a creativity and innovation festival scheduled for April 2019.

Finding inspiration on campus

Kleiankina joined the music department in 2009 as a teaching assistant professor of piano and piano pedagogy, after receiving her doctorate of musical arts from the University of Michigan in 2008. Born in Krasnoyarsk, Russia, she began her musical studies at the age of six, winning composition awards by the age of ten. Today, she is an active solo and chamber music performer with an international career, and has performed with orchestras from Moldova, Romania, the United States and Russia.

The environment of science and research at NC State inspired Kleiankina to develop a recital centered around the theme of space and exploration. She wanted to do something interdisciplinary that somehow addressed science, and resulted in more than a single music recital. "I already had the concept in mind and I knew my dream was to be able to visualize the sound as I'm performing, to help people [connect with the music,]" Kleiankina said. "But I thought this would be too complicated."

When Kleiankina met Polyak by chance at NC State's 2016 Teaching and Learning Symposium, they started chatting about their work and found that they had shared interests. Polyak, co-director of graduate programs in art and design in the NC State College of Design, was one of the pioneering artists experimenting with 3D computer animation over 20 years ago. Today he works with computational generative art, which involves processing signal inputs of various kinds and translating them into visual art using computer systems. His interest in the intersections of the physical and virtual worlds fit perfectly with Kleiankina's vision for her recital.

Building an interdisciplinary recital

To create the computer-animated visual narratives that would accompany Kleiankina's recital, Polyak turned to a process called machine learning, where a computer uses algorithms and mathematical models to progressively improve its performance on a specific task. Essentially, he was training a computer to process the notes Kleiankina was playing and predict what she would play next, and then convert those sounds into visuals in real time. It was complicated by the fact that Kleiankina would be playing an acoustic piano rather than a digital one, so there was no direct input way to get the sound data into the computer. Instead, Polyak had to record her playing each piece and teach the computer to understand the sounds.

"It's not about the accuracy of converting sound into music and the music into perfect visuals. It's relying on the current state of machine learning, the current state of what computers can understand from acoustic waves, how they can interpret, how they can understand music, and just see what happens," said Polyak. "Kind of like how a dancer would not really necessarily understand the musical notes but they would be able to perform based on what they hear and improvise at any point, you make a computer program that improvises based on what is being put into it."

Once Polyak was on board, Kleiankina began researching music to include in her recital. Though trained as an expert in classical and romantic music, she is an enthusiastic performer of new music, and looks for opportunities to commission new works or bring infrequently performed pieces to new audiences. She already knew she wanted to include *Jupiter's Moons* by Judith Zaimont, but she wanted to go beyond the obvious planetary themes. "I wanted not only the pieces that are about stars but also pieces that are about people and human emotion and our paths and exploration of the cosmos and space," Kleiankina said.

She discovered a piece by Pierre Jalbert called *Relativity Variations* that had never been commercially recorded. She intuited that its sparse, spatial feeling would pair well with visualizations of stars. To begin the recital, she selected a piece called *Méchanisme* by Esa-Pekka Salonen, which introduced the idea of humanity's striving to explore space.

Some of the pieces Kleiankina described as avant-garde, using the piano like a percussion instrument or a harp, or accompanied by electronic music, with sounds and a musical language that were new to Polyak. "I was curious to know what my program was going to do with it. If you create a really good machine learning system for pianos that it recognizes the timbre of the string being hit and the note and everything, and then you go there and pick the string or you put an object in there [to change the way it sounds], it's not going to understand it but it's still the same instrument. A glitch is always interesting, whether it's computer generated or human."

Kleiankina also commissioned new works from two of her NC State colleagues – Dr. Peter Askim, director of orchestral studies in the Department of Music, and Dr. Rodney Waschka, director and professor of arts studies in the College of Humanities and Social Sciences.

Askim was thrilled to have the opportunity to compose a new work for Kleiankina, and set out to create music that explored not just the theme of the recital, but also her strengths as a musician. "I wanted to create music that explored her enormous emotional range and her ability to express the complexity of human experience, in all its contradictions," said Askim. "Olga is wonderful as a collaborator – her playing technique is astounding and she can play anything. More than that, though,

Emil Polyak of the NC State College of Design created real time computer-generated visuals to accompany the live piano performance of Olga Kleiankina.

PHOTO BY BECKY KIRKLAND

she is truly determined to enter into the heart of every composer's sound world and musical language. She went far beyond what normal performers do to understand my music from the inside out. Her commitment is truly inspiring."

Reaching new audiences

The performance at ACCelerate: ACC Smithsonian Creativity and Innovation Festival will take place April 5-7 at the National Museum of American History in Washington. The festival is a celebration of creative exploration and research happening at the nexus of science, engineering, arts and design.

Kleiankina is looking forward to sharing the recital with a new audience, and Polyak is glad to have the opportunity to refine his program and artwork. "You don't want to overpower the pianist with the visual," Polyak said. "You kind of want them to integrate and become one. It's almost like stage lighting that you want to emphasize the story with the lighting and the set. Now we have a pretty good recording of the first one, so I can use that as learning data and just feed that in again." He laughs as he adds, "And then probably she's going to play it again slightly differently."

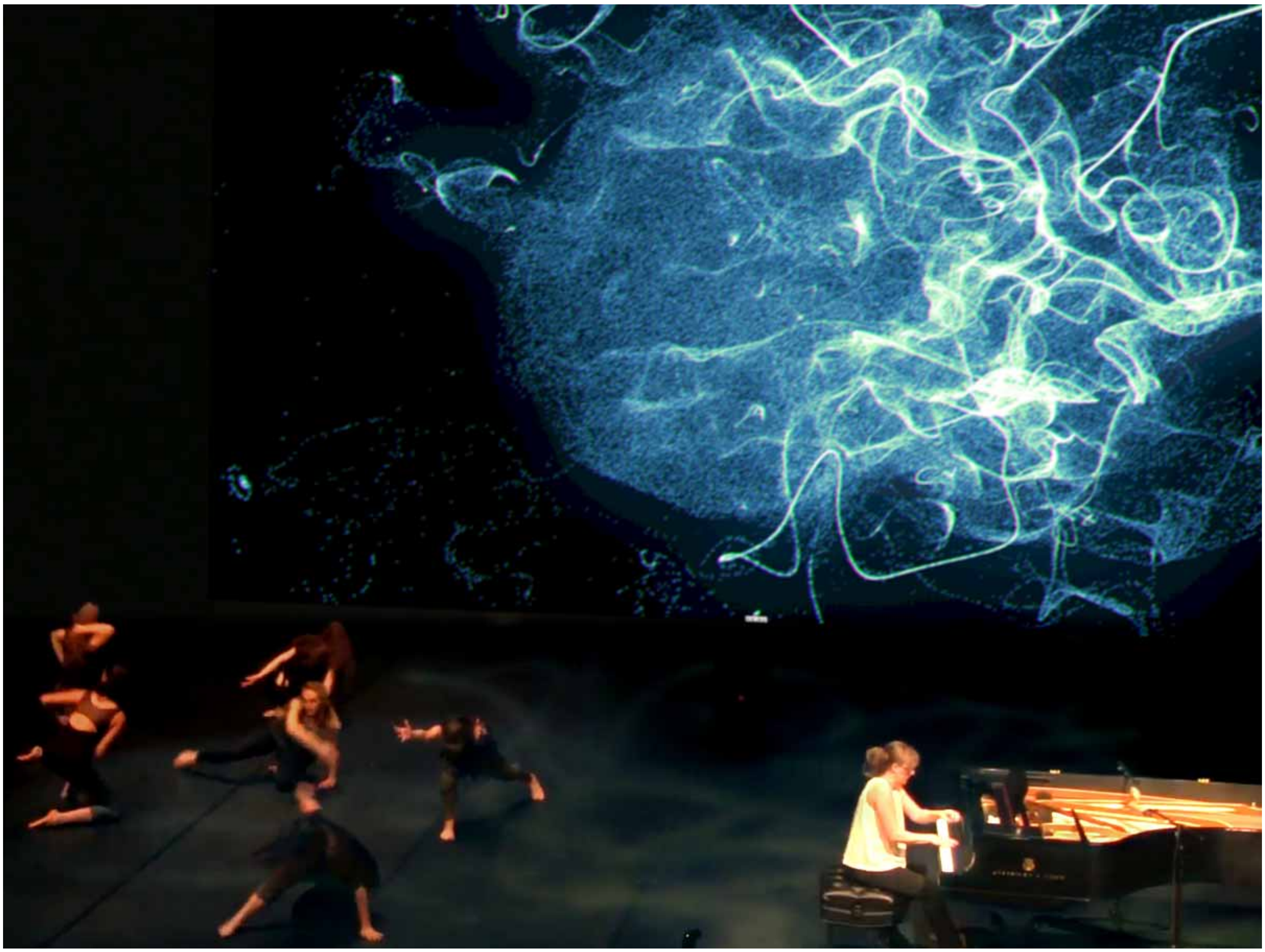
In addition to the ACCelerate Festival in April, Kleiankina will perform the concert at the North Carolina Museum of Art on May 5, presented by Chamber Music Raleigh. The entire concert was recorded in December and will be released as an album in spring 2019 by Blue Griffin Recordings. ■

Erin Zanders is the marketing coordinator for the NC State Department of Music and can often be found volunteering backstage at local community theatres. She is the recipient of Berklee City Music's 2016 and 2018 Emerging Leadership Award.

...OUR PASSAGE TO THE STARS

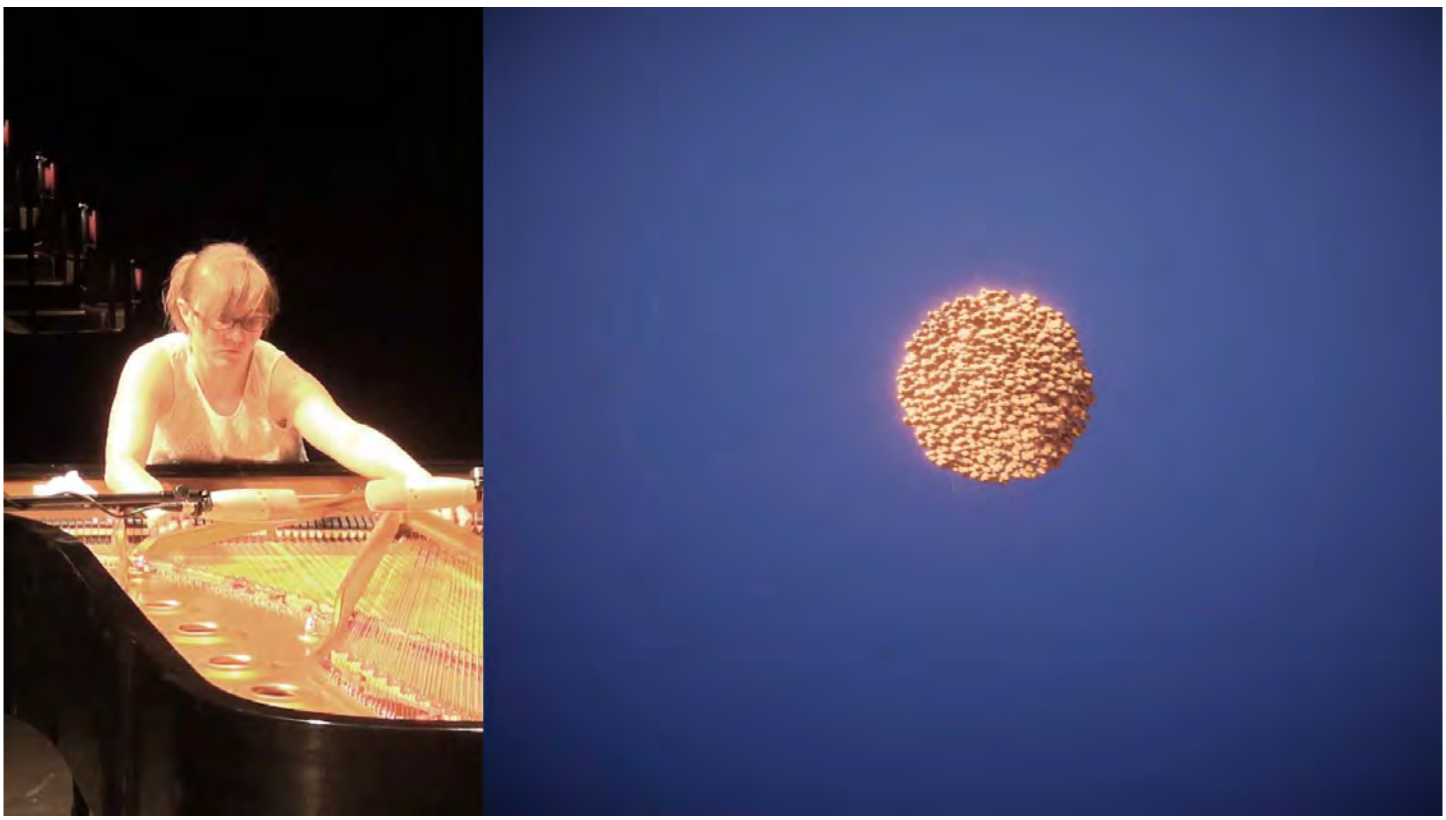
Smithsonian National Museum of American History, Washington DC.

...OUR PASSAGE TO THE STARS



Stewart Theatre, Raleigh, NC

...OUR PASSAGE TO THE STARS



...OUR PASSAGE TO THE STARS

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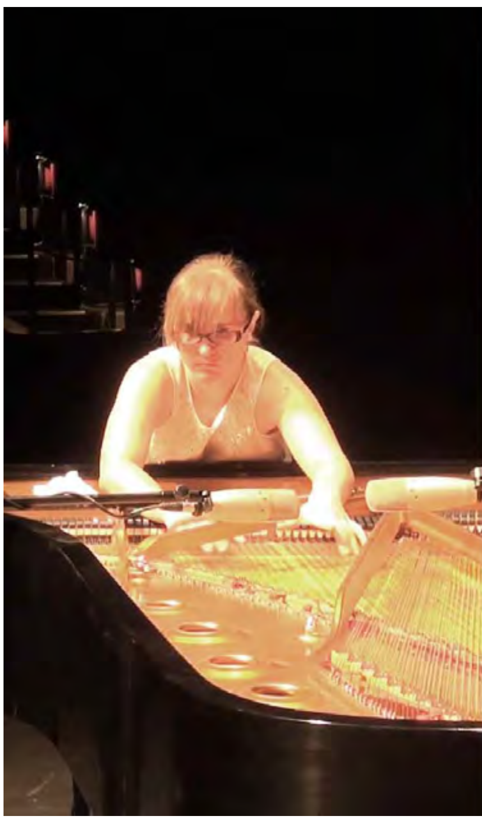

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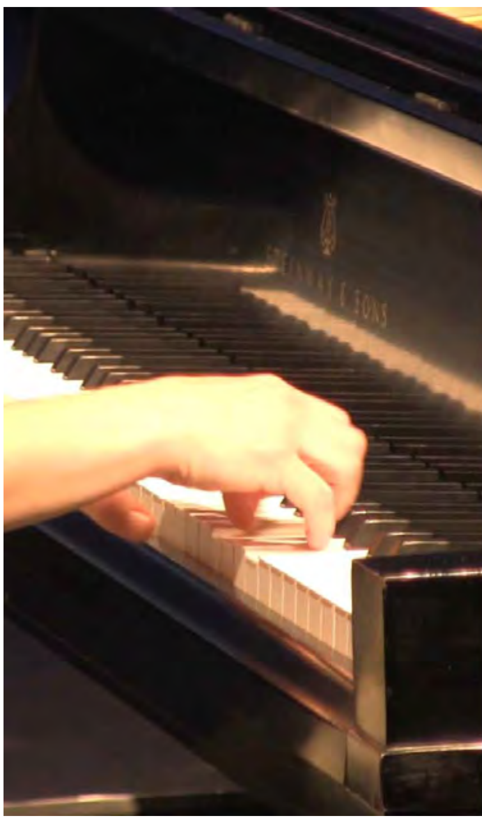

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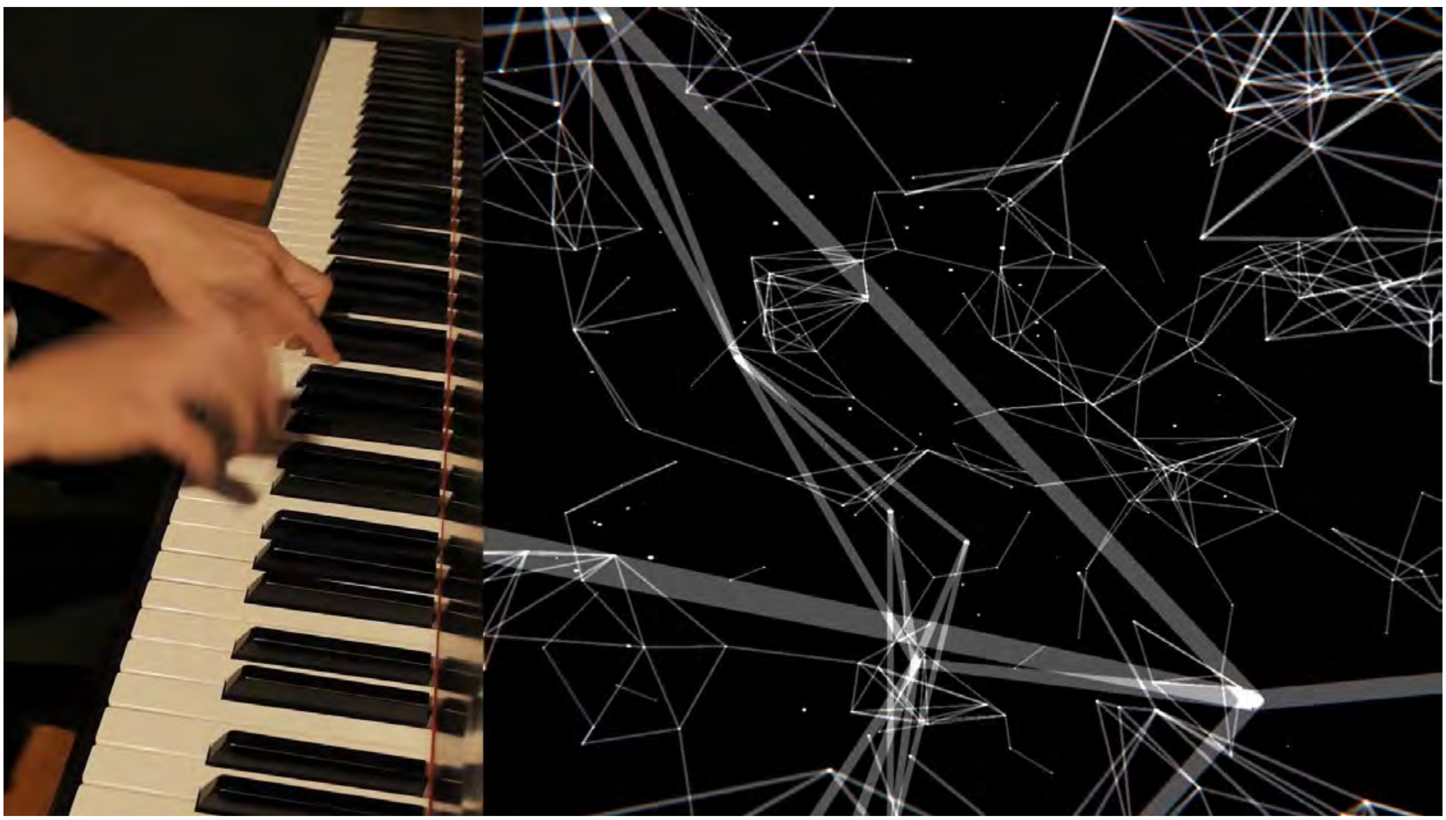

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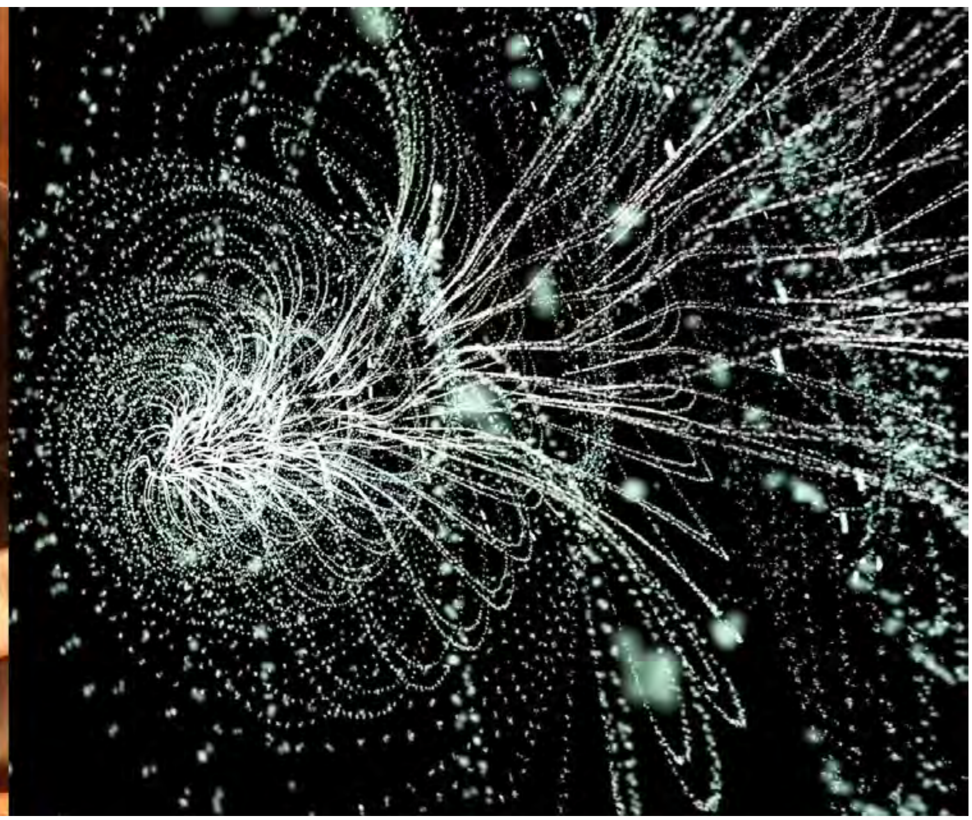


OPTIMIZATION FOR RADIOTHERAPY

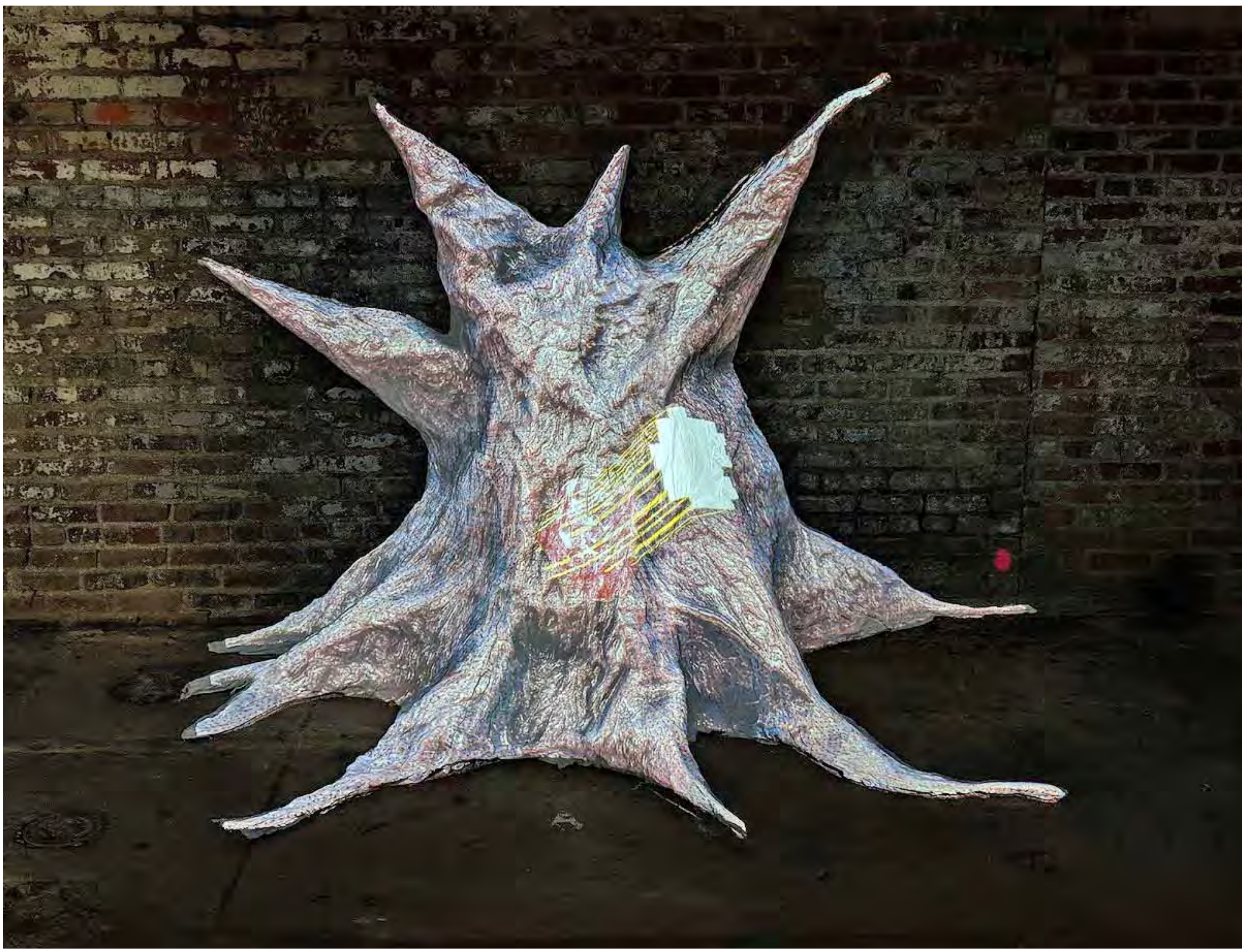
Artist: Emil Polyak
Mathematician: Dávid Papp

How can we use radiation to destroy cancerous tumors without affecting healthy tissue?

Step into this artistic simulation of radiotherapy for the treatment of cancer. As you interact with the piece, critical aspects of the radiation therapy process that rely on sophisticated mathematical optimization algorithms are unveiled. Use the console to direct radiation beams towards the metaphorical tumor using different angles and intensities to avoid damaging the healthy tissue in front of and behind it. This experience brings you face to face with the geometric optimization challenges of radiotherapy.

The key to treating cancer is to destroy as much of the tumor as possible while preserving the healthy tissue. Cut too little and the tumor grows back. Cut too much and wreak havoc on the patient. Recent biological insights and technological advancements are worked into the mathematical optimization models and algorithms for radiotherapy. Conversely, mathematical analysis can lead to medical improvements! For example, our math research has found that the benefit of radiotherapy can be substantially increased by using a continuously modulated radiation beam whose shape and intensity is changing as it is rotating around the patient ("arc therapy"); and designing multi-day treatments that treat different parts of the tumor on each day of the treatment ("spatiotemporal fractionation").

OPTIMIZATION FOR RADIOTHERAPY



Interactive projection-mapped sculpture.

Original design of a user interface controlling a virtual multi-leaf collimator.

OPTIMIZATION FOR RADIOTHERAPY

https://vimeo.com/290174150

Original design of a user interface controlling a virtual multi-leaf collimator.

OPTIMIZATION FOR RADIOTHERAPY

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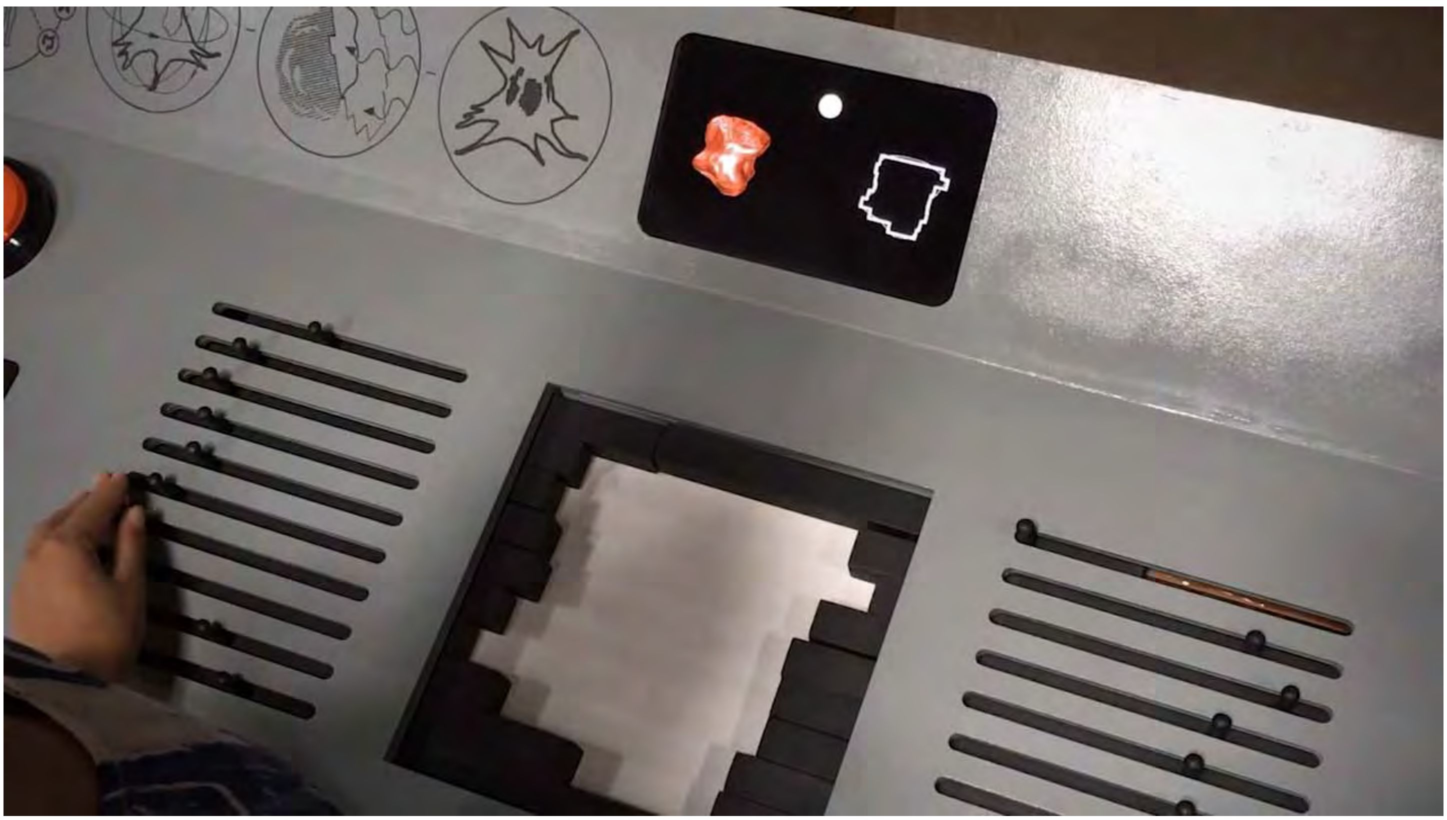

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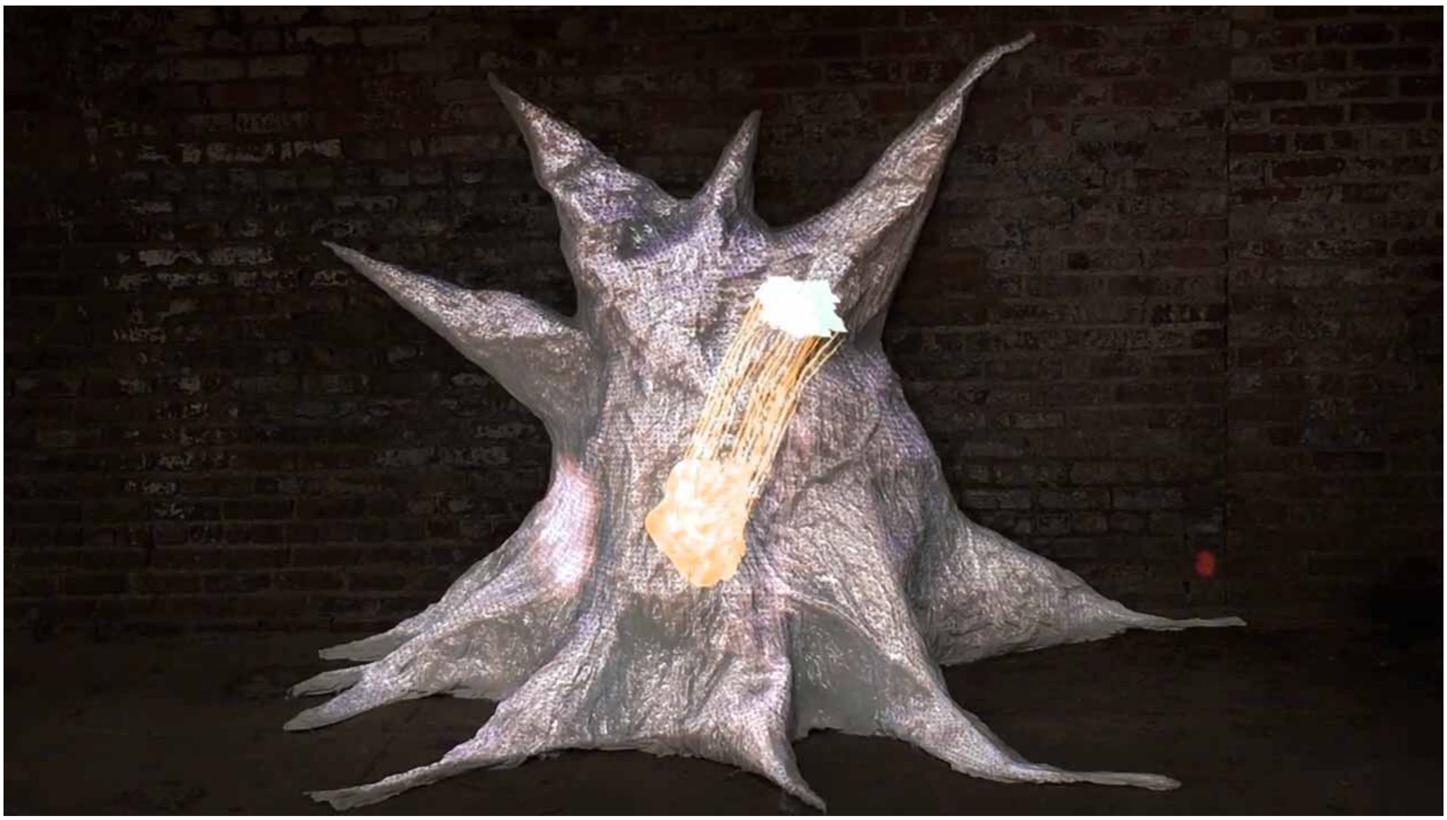

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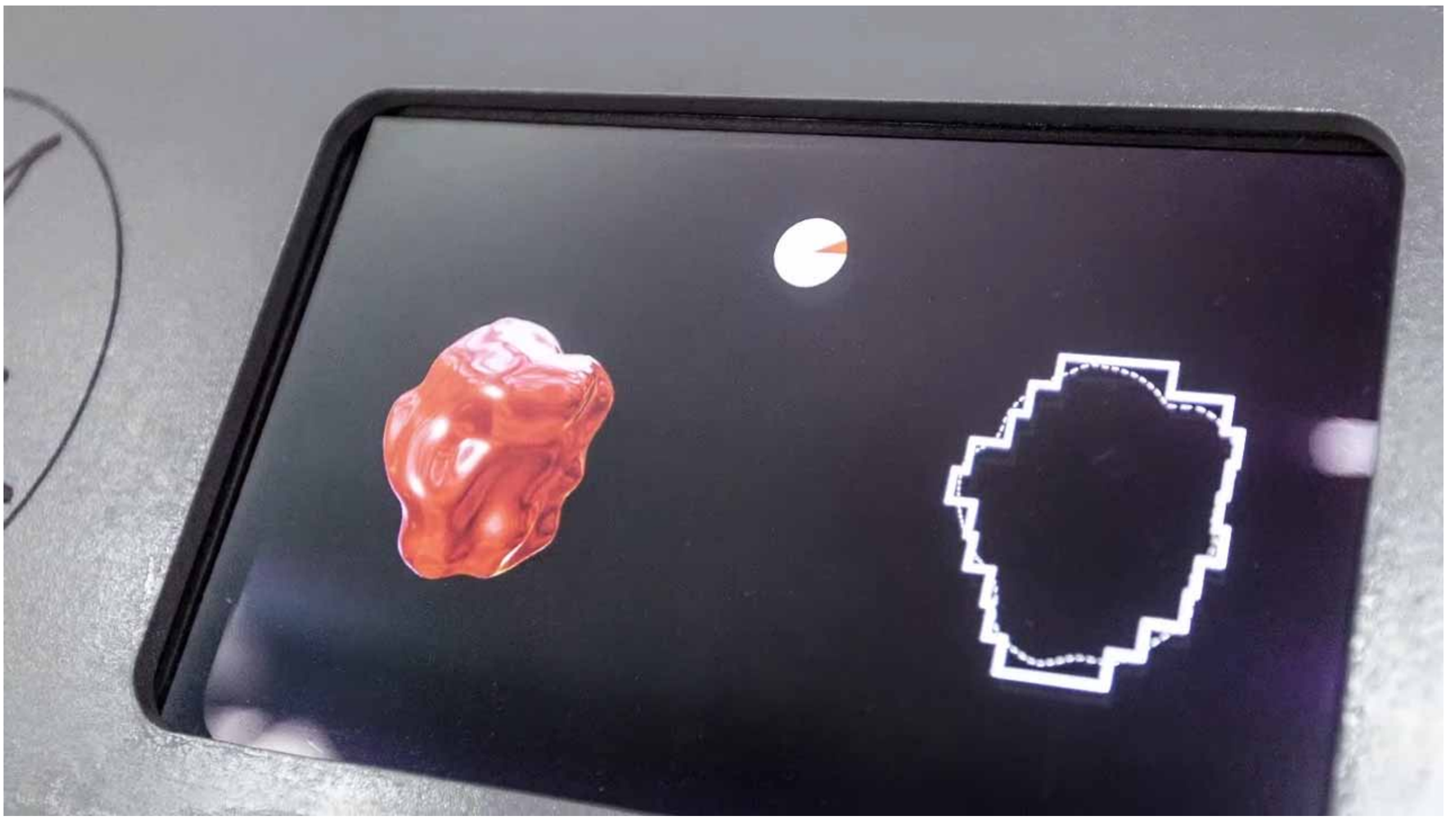
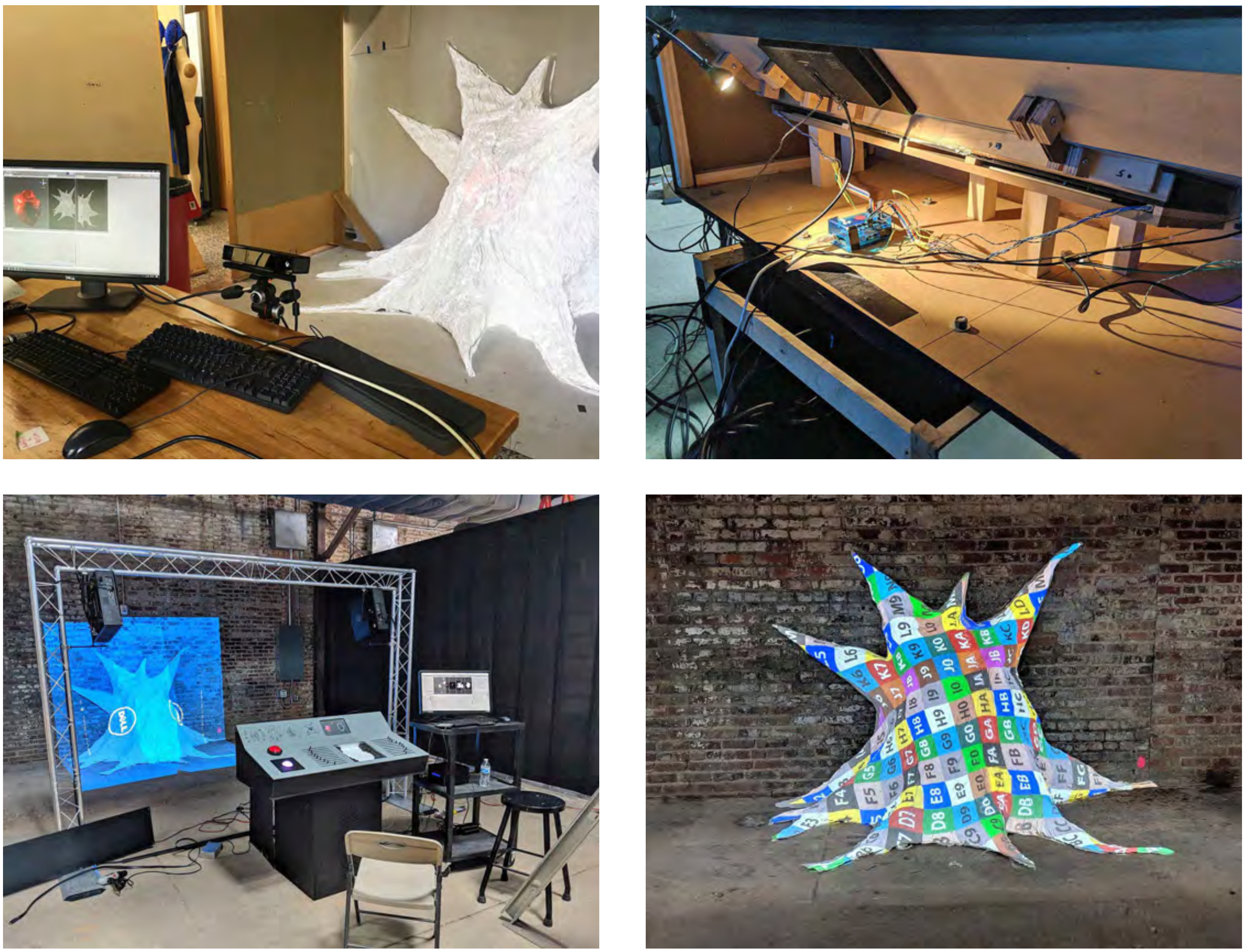


OPTIMIZATION FOR RADIOTHERAPY

Smithsonian National Museum of American History, Washington DC.

OPTIMIZATION FOR RADIOTHERAPY



Development process snapshots.

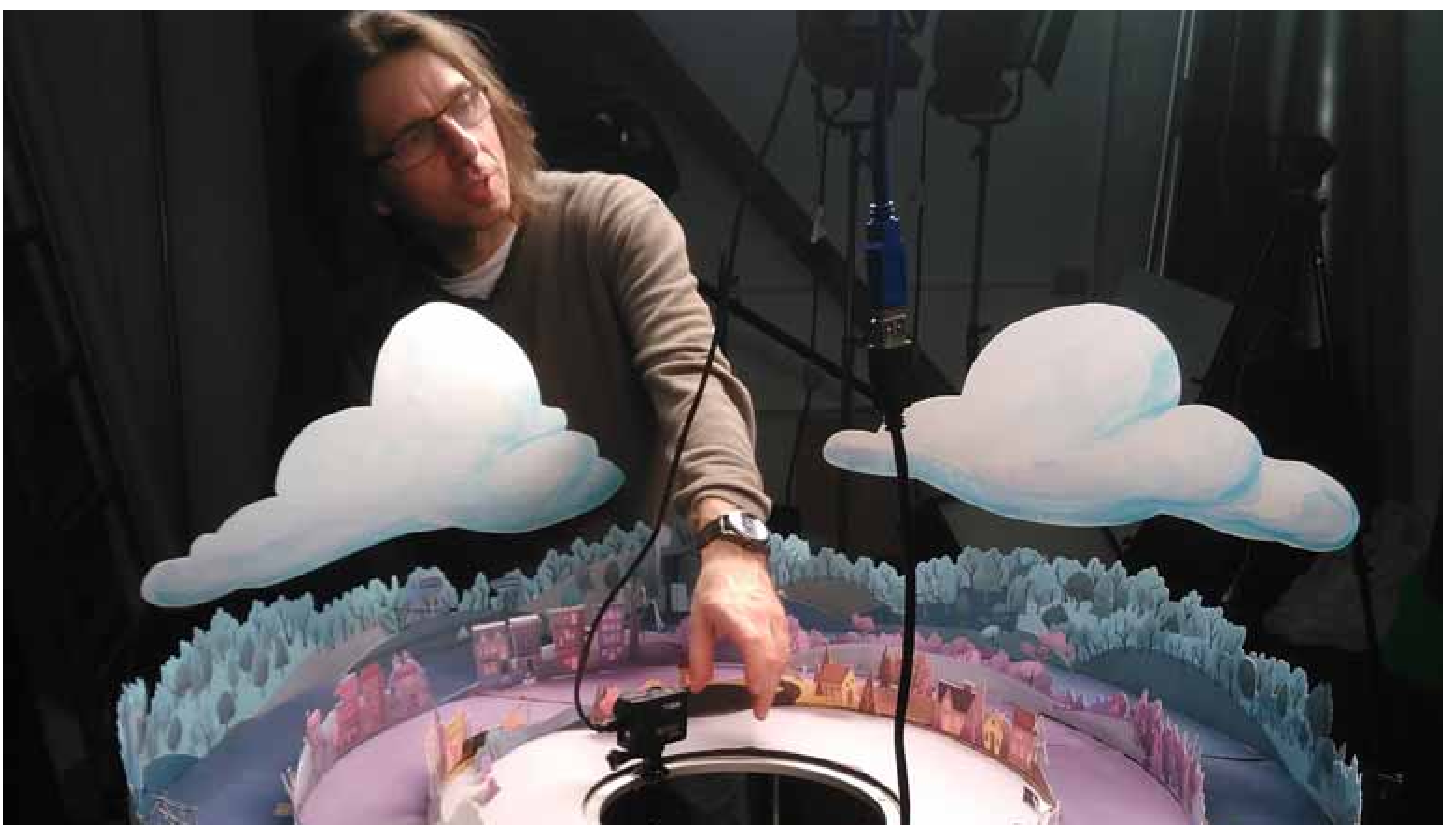
PAPERTOWN VR

Student contributors: Simon Park, Connor Shipway, Hilary Smith, Julia Lineberry, Nattanun Sumpunkulpak, Monica Nguyen, Lucas Gargano

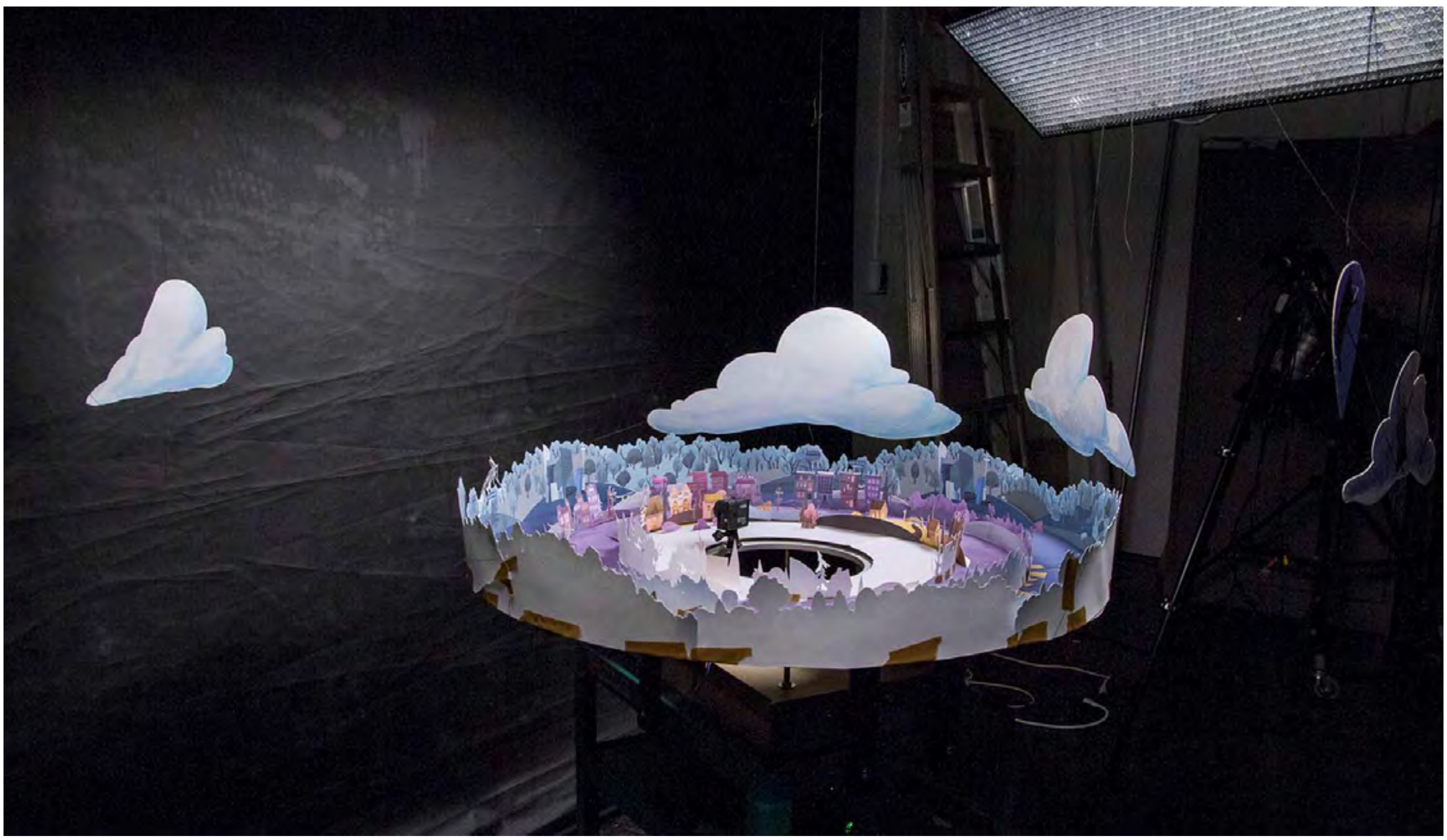
Paper Town VR is an interactive art installation that immerses the user in a miniature 360° physical environment that can be experienced remotely through VR.

The integral part of this project is a handcrafted artwork that adds a human touch to the experience. Utilizing a motorized camera as a scaled-down vantage point, the user can observe the scenery and goings-on of a tiny two-dimensional village as if it existed at a human scale. We created an even greater illusion of depth- using warmer, more saturated colors to make objects come forward and cooler, more muted colors fade them back. Inspired by the 1937 debut of the Disney Multi-Plane Camera, Paper Town VR enlists the effect of motion parallax to add spatial realism to the captured environment. This allows the viewer to use their natural perception of space to more intuitively understand the layout of the environment. Paper Town VR also opens up possibilities for a variety of hybrid and augmented realities, such as overlaying weather effects into the digital viewing space. Finally, since the video stream is live, it provides the opportunity to be used as a live set - objects or characters can be added to the set to appear to the viewer in real time.

Immersive Expressions WebVR Exhibition, SIGGRAPH 2017.



PAPERTOWN VR



PAPERTOWN VR

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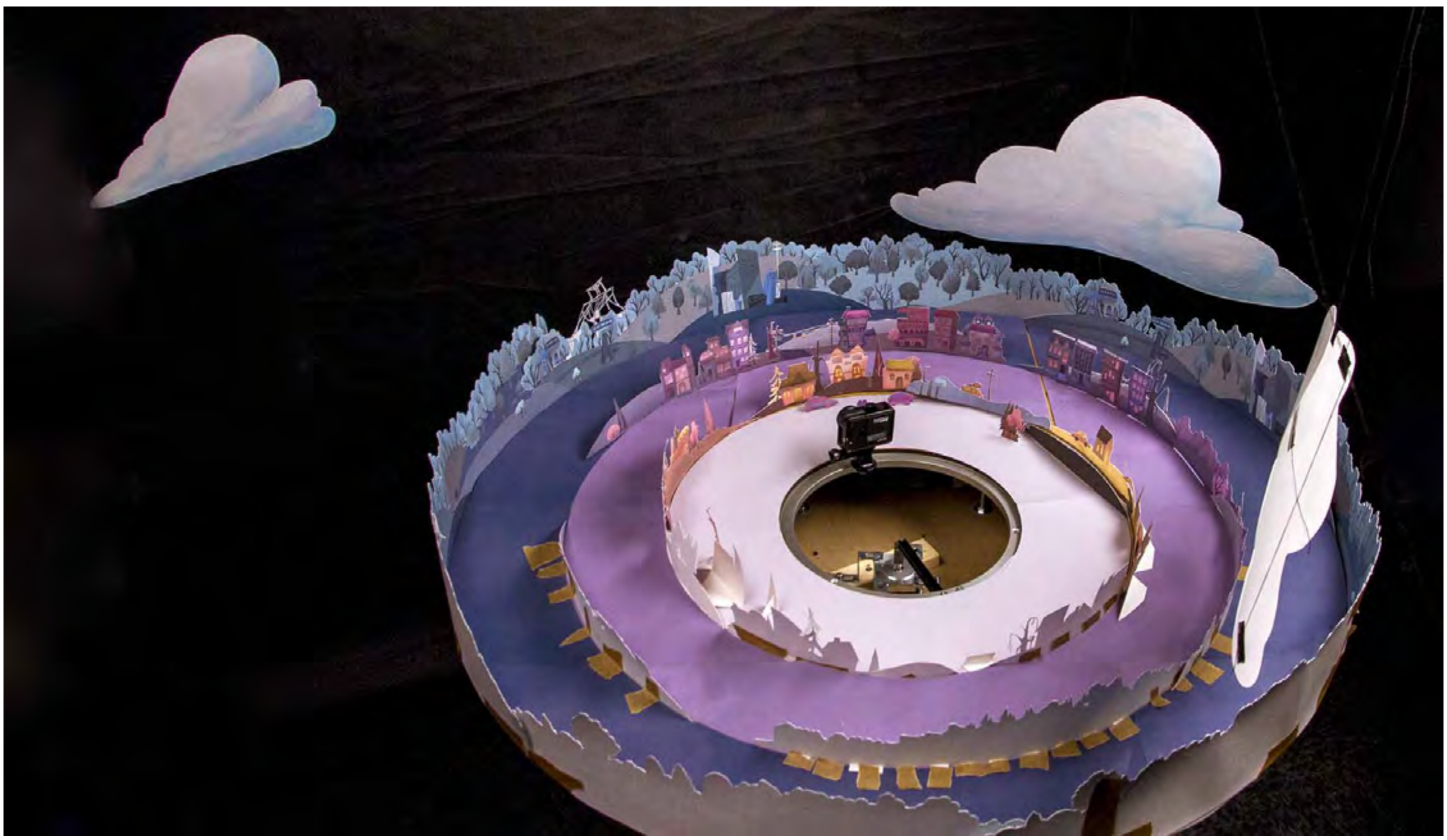

PAPERTOWN VR

PAPERTOWN VR

PAPERTOWN VR

PAPERTOWN VR

TEACHING AND LEARNING CREATIVITY: AUGMENTED REALITY STORYTELLING IN THE MULTIDISCIPLINARY CLASSROOM

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TEACHING AND LEARNING CREATIVITY: AUGMENTED REALITY STORYTELLING IN THE MULTIDISCIPLINARY CLASSROOM

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Abstract

Project-based courses in Art + Design and Computer Science curriculum foster innovation spaces that require creative thinking and multidisciplinary problem solving for unorthodox scenarios and the interplay of technology, arts, and design thinking. It has been recognized that creativity plays an immense role in many if not all fields, and the benefits of thinking “outside the box " reach far beyond the obvious areas such as design, engineering, and arts. The need for an educational paradigm shift is an increasingly salient topic. The challenge to integrate creativity in a curriculum is complex and multifaceted because it requires speculative ideas and methods to support continuous active learning through problem solving in an uncharted territory. It needs a collaborative cross-disciplinary vision and flexibility by faculty, and last but not least, it depends on student buy-in.

“Story-Go-Round” is an experimental physical development platform for producing augmented digital experiences, designed exclusively as an assignment to tell stories in a carousel through interactive control and game play. The goal of the assignment is to provoke creative thinking on a different level by introducing a speculative digital media and game device that has no documentation, tutorials, technological standards nor any examples in mass production, published or shared, and is open to modification/hybridization. The platform is an example of an unorthodox digital interface that presents and communicates ideas that students develop for it ranging from augmented reality, game play, interactive art, to linear narratives and educational experiences.

Keywords: Creativity, Animation, Games, Interaction, Narrative, VR/AR/MR

1 INTRODUCTION

Creativity through storytelling is a fundamental engagement element in most art and design studios in undergraduate education regardless of the nature of the practice. In programs that mix digital media with design, and arts, it is often a complex dilemma. What skills should students practice in order to be successful in present and future job placements? In some cases the direction is defined by the designated instructor’s background, however, this also means that the studio assignments become limited by the experience, technique, style, and other factors related to the instructor. The background of students in these studios often ranges from traditional makers who are experienced in crafts, to computer programmers and game designers with greater technical skills. The educator’s challenge is to engage and provoke both groups to produce a body of work that can be used in portfolios, self-promotion and potentially lead to deeper inquiry for those interested in graduate level research as their next steppingstone. A common mistake, many programs make, specializing in digital arts focus only on present industry practices in only commercial applications that companies use to produce polished work, at the exclusion of unorthodox problem solving and solutions, and innovative thinking through creativity. Creativity is not a directly observable skillset; it is not mentioned as a requirement in most job descriptions for entry level designers. However, creative thinkers generally progress at a higher rate at their careers due to their ingenuity, curiosity and calculated risk taking. They have the capability to become innovators. Understanding these factors we proposed a studio project supported by three professors collaboratively working with students, establishing a cross-disciplinary environment rich in creative potential.

In many areas related to arts creative thinking has been defined mostly by following design thinking strategies.

Osborn's Seven-Step Model for Creative Thinking follows:

1. Orientation: pointing up the problem
2. Preparation: gathering pertinent data
3. Analysis: breaking down the relevant material
4. Ideation: piling up alternatives by way of ideas
5. Incubation: letting up, to invite illumination
6. Synthesis: putting the pieces together
7. Evaluation: judging the resulting ideas [1]

However, such iterative models rely on previously learned skills to discover problems, and usually form solutions using available information. Creative thinking can be also defined as “the compendium of different attitudes, thinking skills and thought processes that increase the probability of pattern breaking and the creation of new connections in our brain” [2]

Hartman argues that what makes this definition distinct is that:

- a problem is not defined unequivocally
- a problem is new and there is no previous experience
- there are information gaps
- the solution needs to be entirely new and different [3]

Creative thinking requires skills such as creative observation, postponing judgment, diverging, developing imagination, and flexible development. [4]

2 METHODOLOGY

The Augmented Reality Storytelling in the Multidisciplinary Classroom is a semester long multi-disciplinary studio project; supervised in a co-teaching model. It utilizes technology that employs an unorthodox combination of elements based on open hardware and open source software. The studio project was designed to challenge the traditional makers and artists as well as the computer savvy student population. The goal of the project was to create a platform that is incompatible with previous experience that students obtained working with various media. It presents new problems, and the information related to solutions is filled with gaps. Our project is titled “Story-Go-Round”, and it is a physical development platform for producing augmented digital experiences, designed exclusively as an assignment to tell circling stories through interactive control and game play. We propose a miniature mechanical and replaceable “carousel-like” stage linked to a game engine, which controls the rotation using a motor as well as streaming a live view of the stage directly into the game environment. (Figure 1)

Figure 1. Completed project exhibited

2.1 Design

The assignment is inspired by the historical aspects of replaceable computer media such as game cartridges, and early animation devices such as the zoetrope, praxinoscope (Figure 2a), kinematofor (Figure 2b), and animated concertina. The stage component is open to continuous physical interaction for an evolving set design, similar to the process used in stop motion animation set building, while the digitized three dimensional version of it is used in the digital augmentation process.(Figure 3)

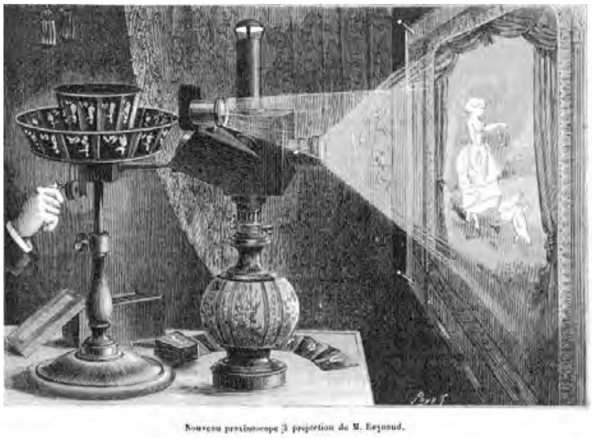

Figure 2a. A projecting praxinoscope, 1882

Figure 2b. The kinematofor made by Ernst Plank

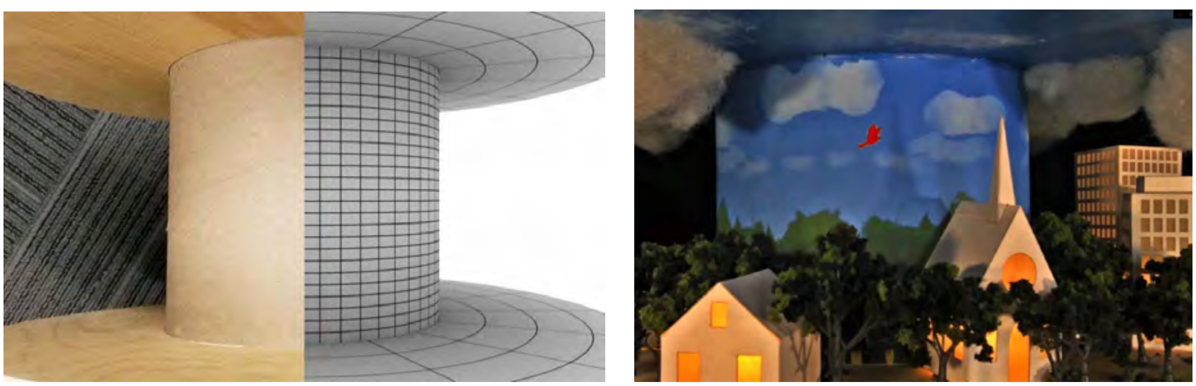

Figure 3. Set design on a circular stage with and augmented, animated bird

2.1.1 Device

The device rotates the set using a stepper motor (Figure 4b) connected to an Arduino microcontroller [5] (Figure 4a), which follows the player's moves in the digital game in real time and acts synchronously. The game is developed in Unity 3D and it receives a high resolution camera (Figure 4c) feed of the set as the background for the game also in real time. The communication is established using Serial (USB) [8], Open Sound Control (OSC/UDP) [7], and memory sharing (Spout) [6], with minimal latency. (Figure 5)

Figure 4a. Arduino board

Figure 4b. Stepper motor

Figure 4c. 4K USB-C camera

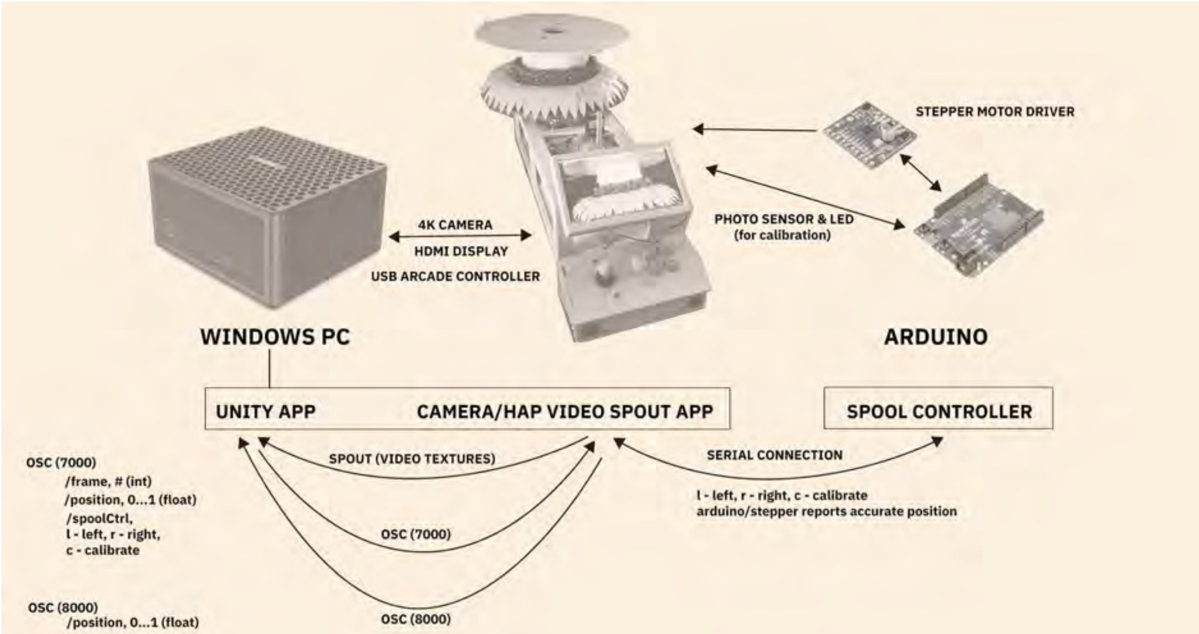

Figure 5. Connections between the physical platform and the computer

2.1.2 Assignment

The assignment asks students to develop a seamless circling narrative by understanding material and spatial choices and their impact as seen through the camera and inside the game engine as logically meaningful and visually appealing components. The narrative can evolve around a defined theme, or simply focus on engaging and innovative play.

In groups, students complete the stage design by curating resources and assembling found objects, or fabricating custom environments, through hand-skills, digital fabrication and simple electronics, before proceeding to produce digital assets, animation and interactivity, including and not limited to game mechanics, control schemes and augmented reality. The assignment lowers the intimidation factor by reenacting the forgiving process of making dioramas and integrating this with foundational skills in game design and programming, and the breadth of digital making. The benefit of this assignment is to think outside the box and leave the comfort zone in order to innovate, collaborate, and learn.

2.1.3 Platform

As part developing imagination, students were introduced to blueprints (Figure 7b), technical narratives, and user experience scenarios. The presented material was open to improvements, and it proposed possibilities rather than step by step guidance. The arcade game style device is playable using an integrated game controller and screen, while the visuals can be shared with a larger audience using projectors. (Figure 7a) The simultaneous presentation of the physical set, the mechanics, and the augmentation through the video game play creates a unique and memorable experience.


Figure 6. Early prototype to the finished platform

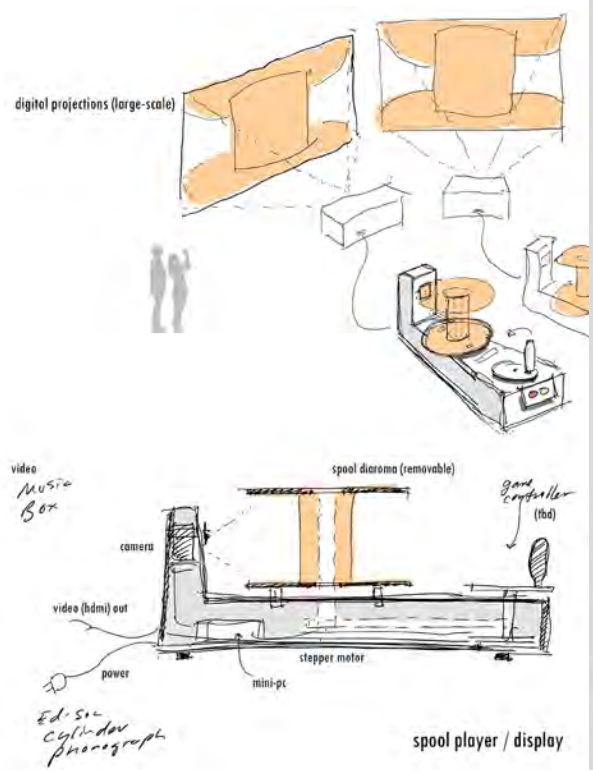

Figure 7a. Platform and projection

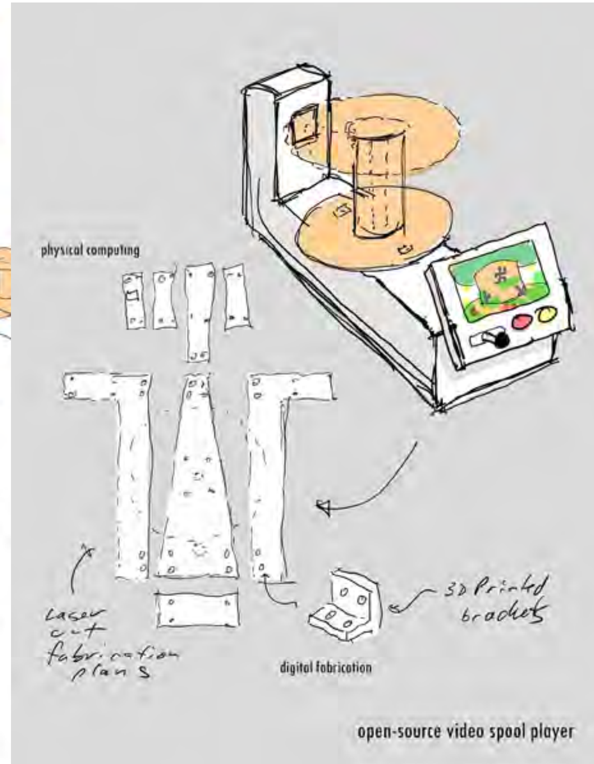

Figure 7b. Device blueprint draft

3 RESULTS

The evaluation of the results was based on completed works, while the real success was seeing those groups of students who gained confidence while fighting through ambiguity outside their comfort zone. Cross-disciplinary collaboration and respect was evident within teams because everyone was in unfamiliar territory.The variety of the solutions reflect the imagination, flexibility and the ultimate goal which is to tell a good story in a visually engaging way no matter what platform is used. The project has gained serious attention at the ACM Siggraph 2020 Conference where we present this work to audiences specialized in computer graphics and related areas.

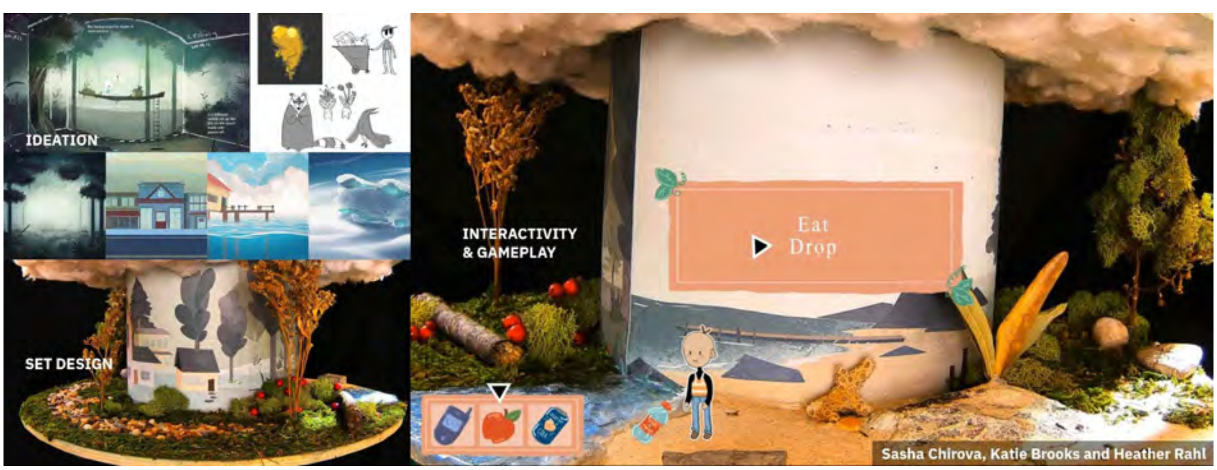

Figure 8. Development process

Figure 9. Result by different groups

3.1 Future work

Future continuation of this work may include more complex mixed reality examples. As 3D input devices such as phones with real time 3D vision become more mainstream it will be an exciting opportunity to utilize those for spatial data acquisition for built sets as well as live players. (Figure 10)

4 CONCLUSIONS

During the semester our students have been introduced to the mentality of the hacker/maker culture in the studio. We all worked together to demystify technology by highlighting the gerryrigged aspect of it, inviting students midstream to complete and connect all components in ways that work for their own purpose. While the project was new, and incomplete to us, the educators too, the most difficult challenge was the student buy-in in the beginning of the process. We realized that previously used methods actually reduced flexibility by focusing too much, and mostly on micro level tasks that employers are asking for specifically such as being competent in software packages, and methods that companies are using. While this is important, we must not forget that the rapid pace of technology advancements also means that entire software architectures become outdated very quickly. Relearning, unlearning, adapting to new ways, and innovating on the way should be above everything.
We realize that co-teaching with three instructors isn't always possible, but it is also not necessary. Educators in arts and design need to gain confidence too in digital areas beyond their specialization.

Figure 10. Augmented with live input

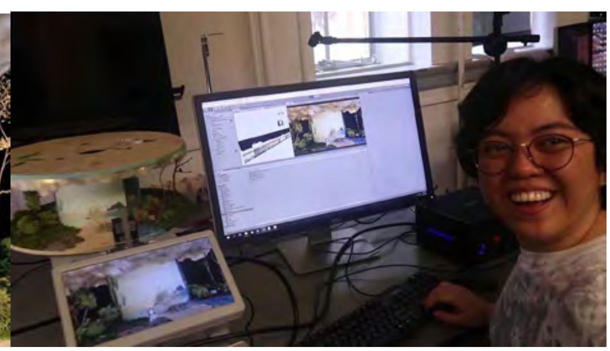

Figure 11. Testing the game play

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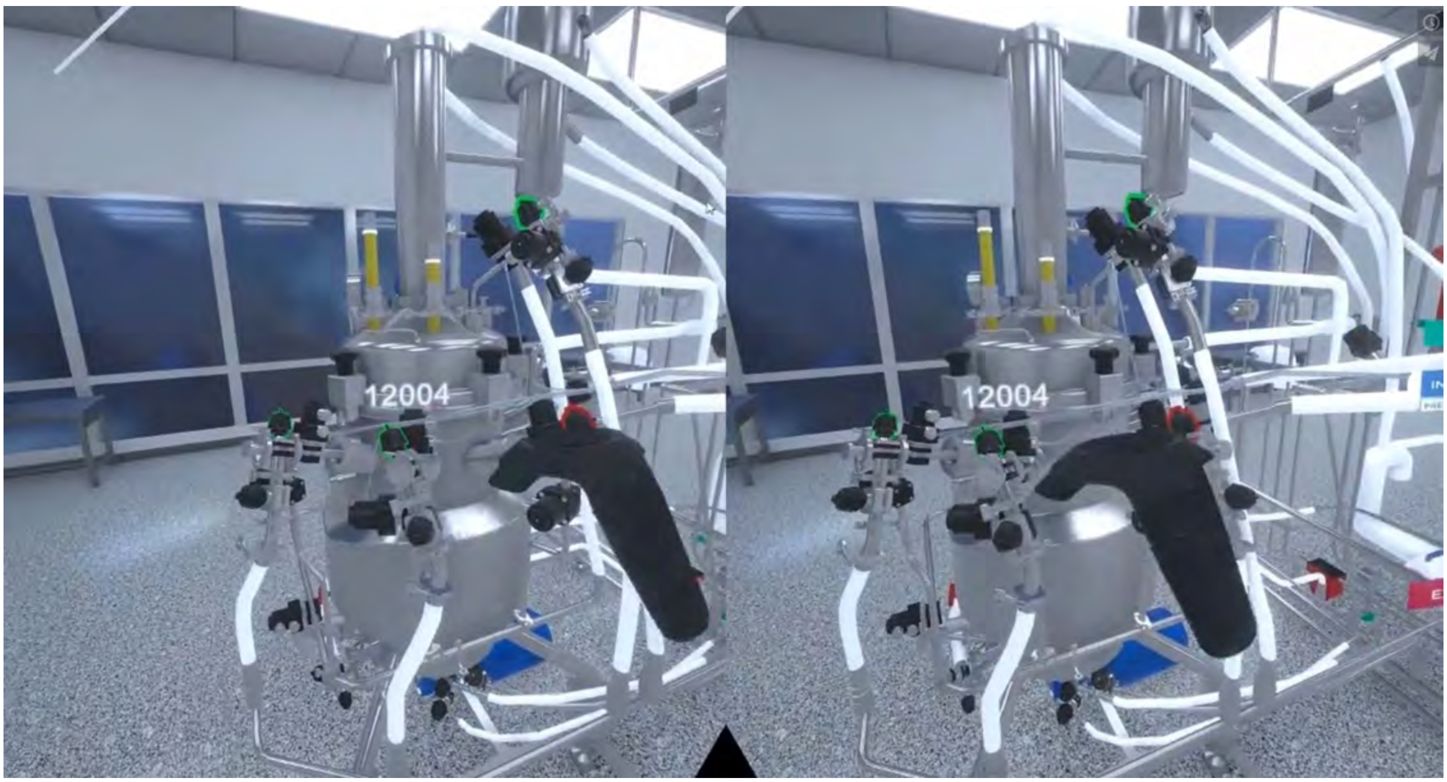
A BIOREACTOR IN VIRTUAL REALITY AND VIDEO GAMES TO ENHANCE THE LEARNING EXPERIENCE IN BIOPROCESS LABS



A BIOREACTOR IN VIRTUAL REALITY AND VIDEO GAMES TO ENHANCE THE LEARNING EXPERIENCE IN BIOPROCESS LABS

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Abstract

A virtual reality (VR) experience and an interactive 360 degree video game about the orientation and sterilization modules of a stainless steel bioreactor (30L) in an university-level biomanufacturing lab were developed using Adobe Illustrator, Autodesk Maya, Unity3D with Playmaker, and HTC Vive. Oculus Quest headset will be used for the VR experience. Instructional design of a hybrid course is underway to incorporate the VR experience and/or video games into existing curriculum. This design is intended to increase the effectiveness, flexibility, and availability of the spaced-out repeated practices for the students, aiming to improve the entire learning experience.

Biomanufacturing is a type of manufacturing that utilizes biological systems to produce commercially important products (e.g., alcohol, biofuels, vaccines, monoclonal antibodies, industrial enzymes, etc.) for consumer usages and industrial applications. As an interdisciplinary field incorporating chemical engineering, biochemistry and microbiology, biomanufacturing plays imperative roles in a variety of fields, such as food, beverage, pharmaceutical and health. The biomanufacturing processes can be divided into upstream (the manufacture of the products) and downstream (the recovery and purification of the products) with the bioreactor or fermentor as the key equipment .

Steam-in-place (SIP), using pure steam for in-situ sterilization of the equipment (e.g., bioreactor and connections) and medium, is critical of biomanufacturing to reduce the risk of product contamination. The SIP operation is very complicated for first-time users, especially for students from non-engineering backgrounds. In addition, limited equipment availability, complicated lab preparation, long cycle time, high cost, and so on make it impossible to offer pre-lab studying, extra practice or post-lab review opportunities for students. Therefore, teaching hands-on SIP operation in a university-level biomanufacturing lab face great challenges. But having an online video game or VR option will greatly aid the students.

Interactive video games allow users to view and interact with the objects on computers and create unique interactive experiences. Virtual reality (VR) further allows a simulated physical interaction with the objects and immersion experience, thus has been used in public education and workforce training in many fields (e.g., manufacturing, food science, biopharmaceuticals, automotive, and logistics). Recent advancement in VR technology has opened up new possibilities to exploit these valuable tools to further efforts to deliver biomanufacturing workforce training and education, particularly the bioreactor orientation and SIP operation labs. Comparing to the video game, VR gives more immersive visual environment experiences that more closely to the “hands-on” experience in the real word.

The objective of this study is to design a VR experience together with an interactive 360 degree video game about the Bioreactor Orientation and SIP Operation, incorporating it into the existing biomanufacturing labs to create a hybrid lab, thus to solve the challenges faced during the existing curriculum and enhance student learning experience.

Keywords: VR, video game, higher education, bioprocess, bioreactor

1 INTRODUCTION

Biomanufacturing, an interdisciplinary field with thousands of years of history, utilizes biological systems (e.g. cells or other living microorganisms) to produce a range of commercially important products for both consumer usage and industrial applications [1] and plays important roles in diverse fields, from food and beverage to pharmaceutical and health. The upstream biomanufacturing processes (the bioprocesses to manufacture the products) with the key equipment (e.g. bioreactor or fermentor) are taught in a variety of university curricula. Biomanufacturing Training and Education Center (BTEC) at

North Carolina State University (NC State) provides unique hands-on academic education and professional training on the biomanufacturing, including the Upstream Biomanufacturing Laboratory , an undergraduate/graduate-level cross-disciplinary bioprocess laboratory course taken by students from BTEC, Department of Chemical and Biomolecular Engineering, Department of Food, Bioprocessing and Nutrition Sciences, and more at NC State. It is an introduction to current good manufacturing practice (cGMP) used by biomanufacturing industries. Students obtain practical experience on key microbiological techniques and processes and study bioreactor design and operation using 30 liters stainless steel bioreactors. The lab modules include bioreactor orientation, scale-up design, cleaning, media preparation, sterilization, and fermentation (batch and fed-batch growth) of a recombinant *E. coli* for the production of green-fluorescent protein (GFP). However, students experience extraordinary challenges in the hands-on lab training environment because the extreme complexity of the bioreactor system and operation procedures as well as factors such as limited equipment/material/supportive personal availability, long cycle time, and high cost make it impossible to offer preview, after-lab practice or make-up of a missing lab session. One-time lab exercise is not enough for students to comprehend such complicated bioreactor operations [2] while researches have shown that space-out repeated practices is important for knowledge retention [3]. In addition, students are so afraid of making mistakes that they tend to observe the instructors to demonstrate the operations instead of executing the procedures themselves, jeopardizing the goal of “hands-on” operation and learning objectives of this course.

Both interactive video games [9] and virtual reality (VR) [10] have been used in education and workforce training in many fields such as manufacturing, automotive, logistics, and medicine. Video games allow users to view and interact with the objects on computers while VR creates unique immersive interactive experiences that more closely to the “hands-on” experience in reality and even present information not attainable in the real world by integrating the human motion. Through synthetic representations of physical spaces, objects, and interactive mechanisms complex procedures can be simulated [11]. The integration of VR systems is a cost effective solution in many cases [12], and provides a more natural way of learning compared to consuming other media such as videos or animation [13].Those technologies not only make a complex topic attractive to users but also increase flexibility and accessibility in education and training. Recent advancement in them makes it possible to deliver biomanufacturing workforce training and education in virtual environment and enhance student learning experience in the bioprocess labs, providing more flexible and accessible practices in the virtual environment.

The aim of this project was to create an immersive experience of bioreactor in virtual reality and video games for students to have an easier time acclimating to the lab bioreactors and familiarizing with individual components and operation procedures prior to their first time with the bioreactor in class as well as reinforce the learning objectives by reviewing the lab modules in virtual environment after the labs. The video game and VR design focused on the Bioreactor Orientation and Steam-in-place (SIP) Operation lab modules because the bioreactor orientation is the fundamental exercise for students to become proficient with the essential components of a cGMP 30 L bioreactor and ancillary systems while the SIP operation is the most complicated lab with highest student failure ratio that also negatively affects the subsequent labs among all lab modules in the Upstream Biomanufacturing Laboratory course. The Bioreactor Orientation module includes modeling both the bioreactor and ancillary equipment (air supply system, jacket temperature control system, water and steam supply, etc.), while the SIP module create interactions with both the bioreactor and the control panel. Students can walk around the bioreactor in the virtual environment, identify key elements of the bioreactor, locate ancillary equipment, and operate the SIP procedure to sterilize the bioreactor.

Simulated virtual bioreactors with focus on the fermentation production data simulation and prediction of the fermentation results have been used to teach fermentation process [3-5]. But our virtual bioreactor focused on bioreactor design and interactive operation aspects in virtual environment, which is a novel direction. To our knowledge, there has been no cGMP 30 L stainless steel bioreactor system built in virtual reality for bioprocess lab education and training.

2 METHODOLOGY

The virtual bioreactor environment design includes two phases: video game design with 3D modeling of the bioreactor and VR design of the bioreactor. The aim was to be accurate and accessible.

2.1 Video Game Design

A 3D model of the bioreactor was first constructed in Autodesk Maya after thorough documentation of the unit through photographs of the unit from multiple angles, including documentation focused on each connecting pipe and label, as described in detail in previous publications [2]. During the model process, the photographs were also used to determine comparable size and color in an effort to make the model as accurate as possible. The interactive elements of the project was built using Unity and the Playmaker asset, based on the step progression of the lab module.[2]

2.1.1 Video Game for SIP Operation Module

The SIP, a in-situ sterilization of the equipment with pure steam, is critical to reduce the contamination during bioprocess [6]. It includes equipment heat-up, sterilization (maintaining minimum temperature 121°C for a specified time), and equipment cool-down, interacting with the bioreactor control panel and dozens of valves, which makes it very challenging for first-time users.

Through the interactive script in the video game, the user is able to prompt the touchpad of the bioreactor control panel in the same fashion that would be presented to them in the lab. Animations were also built into the model, causing the knobs to turn when prompted to simulate the actions that will be taken during the sterilization protocol. Indicators were added, highlighting which components were necessary for the user to proceed in the process. A label was also given to each manual valve involved in the SIP on the bioreactor (Figure 1), replicating the tags on each valve of the original bioreactor. These labels are used in the protocol, and familiarity with the labels will greatly help the process of following the sterilization protocol.

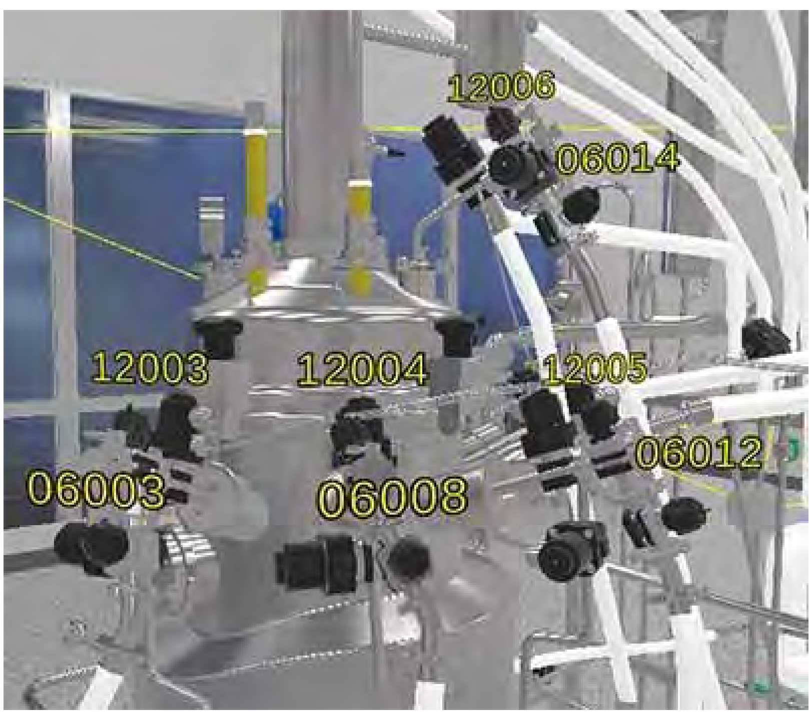

Figure 1. Bioreactor SIP manual valve labels.

An interface was built so that the user could easily reference the available controls, instructions, and to exit the program. The controls referenced include the navigation keys, selection tool, and a crouch feature that was added so that the bottom of the unit could be viewed more easily. The instructions update as the user progresses through each stage of the sterilization module. At any point during the process, the user can easily select the instruction button from the menu and follow the guidance for the next step. For aspects of the interface that were commonly missed by users, including the specific highlighted buttons on the bioreactor computer screen and valves on the back of the unit, arrows were added to provide further clarity.

2.1.2 Video Game for the Bioreactor Orientation Module

After the sterilization interaction was complete, a separate orientation interaction was built. This section of the game focuses on labeling each key component of the bioreactor system, based on the Bioreactor Orientation lab module protocol. Labels for the main components of the bioreactor, as well as utility pipes and components of the ancillary equipment behind the bioreactor unit were included. A counter was also added to show the user how many labels they have left to reference before the game is complete. As the user selects each component, it is highlighted, and the label is shown above it (Figure 2).

This interaction was built with the user of Unity's box collider system. Since the shape of the model was intricate and largely centered in one area, the unit was divided into boxed sections. When the user hovers over each section, the section within the eye line of the user is prompted. The objects that served the greatest challenger were the numerous pipes in the middle of the unit, overlapping with each other in the line of sight of the viewer. To be certain of each pipe, it will be necessary for the user to circle the unit to get close to each pipe. Another challenge was the small valves surrounding the bottom of the device. To get a clear view of each selected piece, the user will need to crouch close to the valves. If selected from far away, the small prompts are easily triggered together.

The script used to build the Orientation interaction will allow for further development, including a game that will require the user to label each piece individually instead of having the label shown to them.

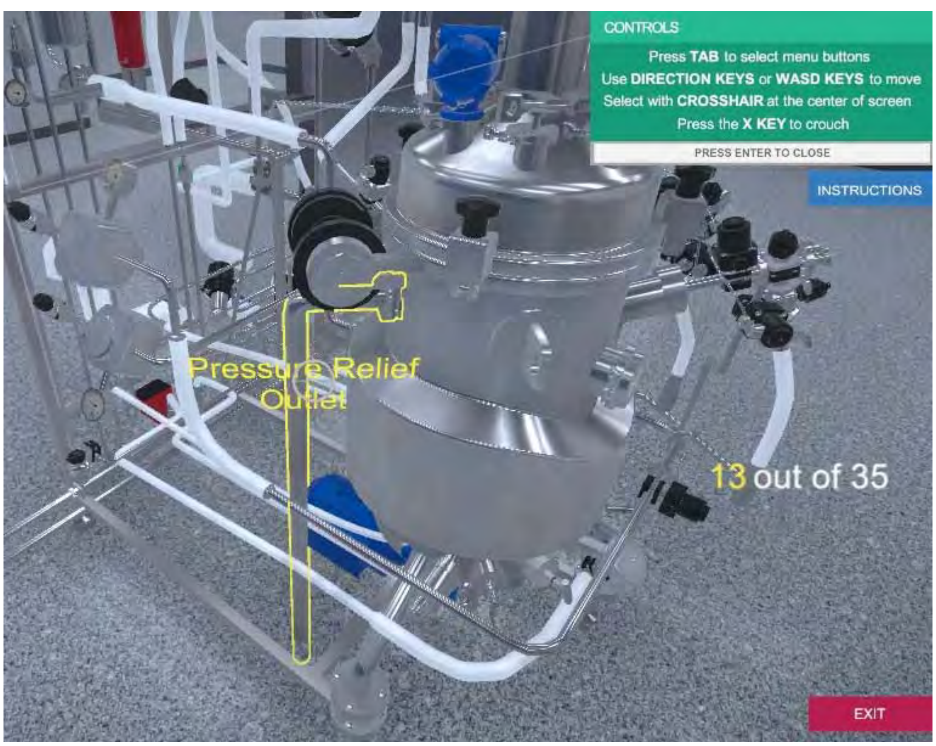

Figure 2. Video game design for Bioreactor Orientation module: the display in the game when selecting pressure relief outlet.

2.2 VR design

The VR design is conducted in HTC Vive and will later be modified to be compatible in the Oculus Quest, a new PC-free VR headset scheduled to release in 2019. A standalone all-in-one VR headset will provide more flexibility for students to check out the headset to practice. The game aspects built during the initial game design largely translate over to VR.

The challenge of VR is to create an intuitive interface that allows the user to select prompts without the use of a mouse. Further research was done through other VR examples, to understand how interactive menus had been accomplished in previous VR projects. Those examples often had a separate screen prompt close out the VR environment and switch to a single menu screen, or had a menu that was prompted by a gesture from the user. For this project, the solution was to enable the user to cycle through the menu with a button on the Vive-HTC controller. This would not interfere with the selection tool of the controller, but would still allow easy access.

With the development of VR in the project, several components of the original game conflicted with the VR set up. This included any click based interactions and the camera built in Unity to provide the game visuals to the user. A VR camera setup was needed instead to properly scale the model to the HTC Vive headset. For click based interactions, the selection will instead be tied to the movement of the Vive controllers. Since this will be tied to the user’s hand movements, it will be a much closer replication of the real world interaction with the bioreactor screens. Users will have a clear concept of the scale of the monitor and how to interact with it.

3 RESULTS

Both the video game and VR allow students to preview and review the topic without time limitation, extensively interacting with the virtual environment.

3.1 Final video games of the SIP and bioreactor orientation modules

Figure 3 illustrates the final bioreactor model in the video game. The video game version of the SIP Operation (Figure 4 and Figure 5) and Bioreactor Orientation (Figure 6) modules now has a running model, which can release to students after further testing. The game is built as two separate Unity scenes, one for each module. The game following the SIP protocol runs the user through the sterilization process by interacting with both the simulated control panel and the valves on the bioreactor and ancillary system. The game following the Orientation module is able to help the user locate and familiarize with the parts of the key bioreactor components listed in the original lab module in reality. The current Bioreactor Orientation game only includes the tutorial mode, i.e. using instructions to learn each bioreactor component). The future version will include the competition mode, i.e. fulfilling the tasks related to bioreactor orientation. For example, the game randomly generates names of components for students to locate and whoever use the shortest time to find all components correctly will become the winner of the class to earn extra credit.

Figure 3. Final bioreactor system model, including the bioreactor, control unit, ancillary equipment, and utility pipes, in the video game

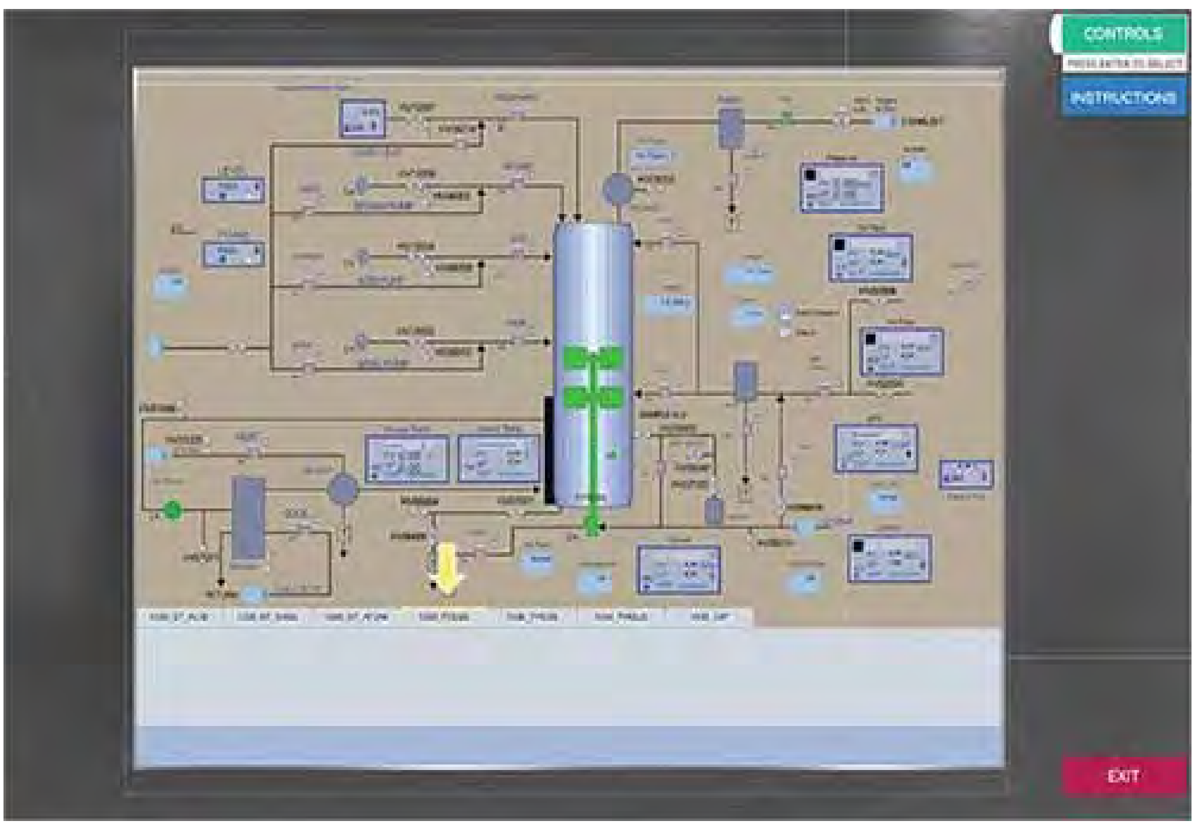

Figure 4. The SIP Operation game in Unity: a sample screen of the control panel at the beginning of the SIP procedure

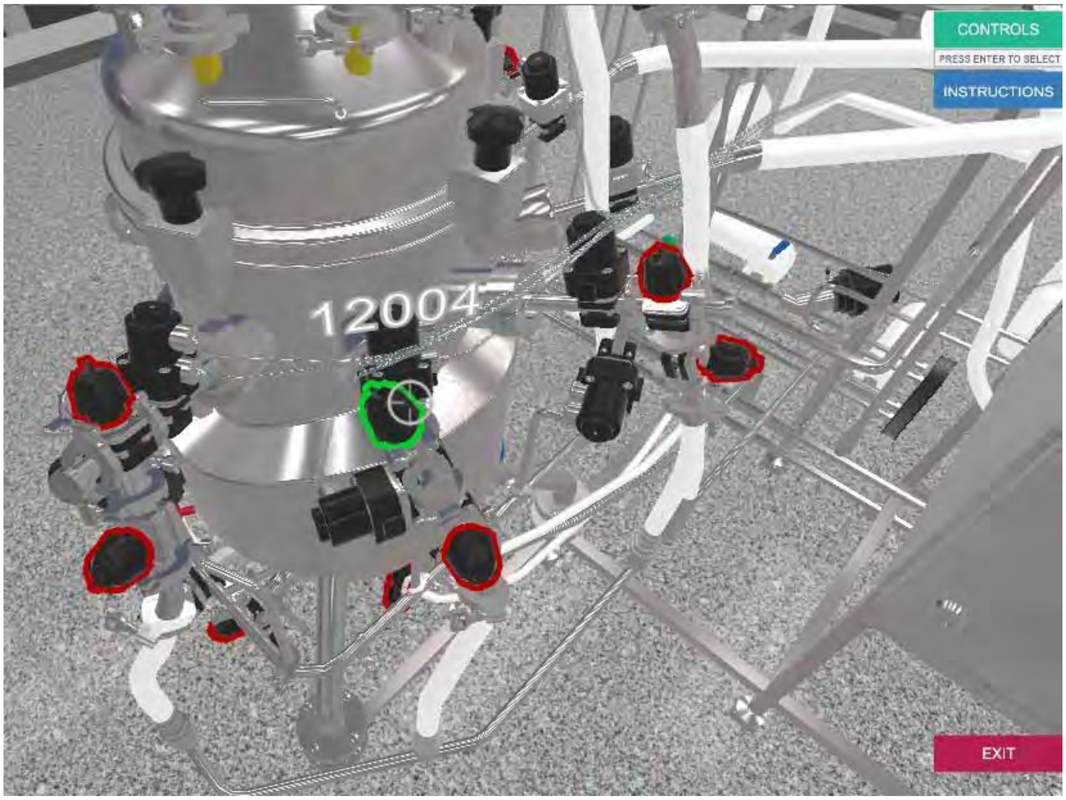

Figure 5. The SIP Operation game in Unity: a sample scene of the manual valves highlighted for interactions (Valves that need to take actions (close or open) on are highlighted in red and changed to green color once correct actions are completed.)

Figure 6. The Bioreactor Orientation game: a sample scene when the pumps are selected in the game

3.2 Final VR of the SIP and bioreactor orientation modules

VR gives more immersive virtual environment experiences compared to the video game. The Virtual reality (VR) uniquely allows the experience of physically interacting with the bioreactor, giving users a much clearer understanding of the scale of the unit, and how to move while proceeding through the protocols (Figure 7). In a VR environment, certain controls are no longer necessary. The user moves of their own free will, and can easily step closer to get a better look at the components, or crouch down to see pieces that are out of the line of sight. Overall, the VR experience gives a much closer experience to the actual bioreactor lab, and prepare them for the module before stepping into the bioreactor lab.

The VR hand controls are used by the user to engage with the 3D space. While the game version uses the mouse click to simulate physical interaction with the unit, VR is able to simulate the depth of real world interaction. The experience of the touch screen monitor is replicated by touching the controller to the button on the screen. The user is also able to user movement to their advantage when selecting components within the bioreactor.

The benefits of this project have been the ability for students to run through the bioreactor protocol multiple times if needed, without the use of lab resources, of the extensive amount of time it takes to run the full SIP protocol in the bioreactor lab. Prior to entering the lab, students have the ability to be comfortable with the protocol and the physical components of the bioreactor. The Orientation module familiarizes students with the many components they will be handling in the lab. This familiarization helps keep students from being intimidated by the unit, so that they can instead focus on the process.

Figure 7. The bioreactor system in virtual reality

3.3 User experience feedback on the beta version

A beta version of the game design was tested with current lab students and professionals in instructional design and media design from DELTA (Distance Education and Learning Technology Applications) at NC State. Students and professionals were impressed by the likeness to the physical lab, and showed interest in the implementation of the project. Several features of the game were included after the initial student feedback, including clearer signifiers and a crouch feature.

A challenge of the implementation of the game is in its file size. Several students had difficulty accessing the game when provided by a web server do to lag. For both the video game design and the VR design, the student will need to have a simple way to access the file without processing issues due to internet lag.

Further user experience testing of the final version of both the video game and VR will be completed in the summer of 2019 with the final project to determine the best option of accessibility for students, and how well the students are prepared for the lab after experiencing the game system.

3.4 Hybrid lab curriculum design

In order to convert the Upstream Biomanufacturing Laboratory into a hybrid lab providing both hands-on lab experiences and virtual training in both the video game and VR for review and practice, the course map template and online syllabus template provided by NC State are used to conduct an instructional design, focuses on the following steps: develop and update the Course Objectives matching with Bloom's Taxonomy [8], identify course Modules, develop Module Objectives (MO) and indicate course objective alignment to each module objective, list Learning Activities, and add Assessments. A website that hosts all virtual bioreactor training materials is designed in Wordpress (https://virtualbioreactor.wordpress.ncsu.edu/), including not only the video game and VR for the virtual bioreactor practice, but also instructional information about the learning objectives, lab safety, and a 360 degree virtual tour to the BTEC facility. Students can follow the instructions on the website to complete Bioreactor Orientation and SIP Operation lab modules at flexible time and flexible learning pace to preview, review and repeated practice of the lab exercises. The immersive virtual environment is expected to help students perform lab activities virtually, prior and/or after the real life hands-on biomanufacturing lab, helping them to retain the concepts and operations as well as practice repeatedly to minimize mistakes. The hybrid Upstream Biomanufacturing Laboratory will become available for students in the fall semester of 2019.

3.5 Future work

To evaluate the benefits and drawbacks of the video game and VR on students learning experience, design of learning outcome assessment using both qualitative and quantitative assessment methods are underway and data will be collected from both students and instructional team during the future labs. These results will further help to improve the design of the bioreactor in virtual environment.
The long term goal is to develop more interactive virtual biomanufacturing lab modules using video games, VR, augmented reality (AR) and other technologies to eventually create either a hybrid Upstream Biomanufacturing Laboratory course with all the lab modules available both in virtual environment and reality or a standalone online virtual biomanufacturing laboratory course. By adding fermentation process simulation features [3-5] to the current bioreactor setup, the virtual bioreactor can expand from the macro-level bioreactor operation lab exercise to micro-level simulation of microbial pathway and fermentation production.

4 CONCLUSIONS

In order to overcome the challenges faced by the instructor and students in an university-level bioprocess laboratory and enhance student learning experience, a cGMP 30 L bioreactor in virtual reality and interactive video game for the Bioreactor Orientation and SIP Operation lab modules are successfully designed to supplement the existing hands-on lab exercises. This project creates an environment that aims to accurately represent the physical bioreactor lab, providing a novel solution for the challenges of the bioprocess lab curriculum, allowing students to gain experience using the unit outside of the classroom. User experience feedback data and assessment data will be collected to evaluate the effectiveness of the virtual lab option in the hybrid lab curriculum. Future plans include further developing more virtual bioprocess lab modules using video games and VR in both macro-level bioreactor operation and micro-level fermentation pathway. The virtual labs can be used in other biomanufacturing courses in diverse disciplines including but not limited to (bio)chemical engineering, food science, and environmental engineering, allowing students to preview/review the labs and even practice operation modules that cannot fit into the regular lab time due to constraints of time, money, and support personnel. It will increase the effectiveness, flexibility, and availability of the bioprocess education and training for the students, and thus improve the entire learning experience.

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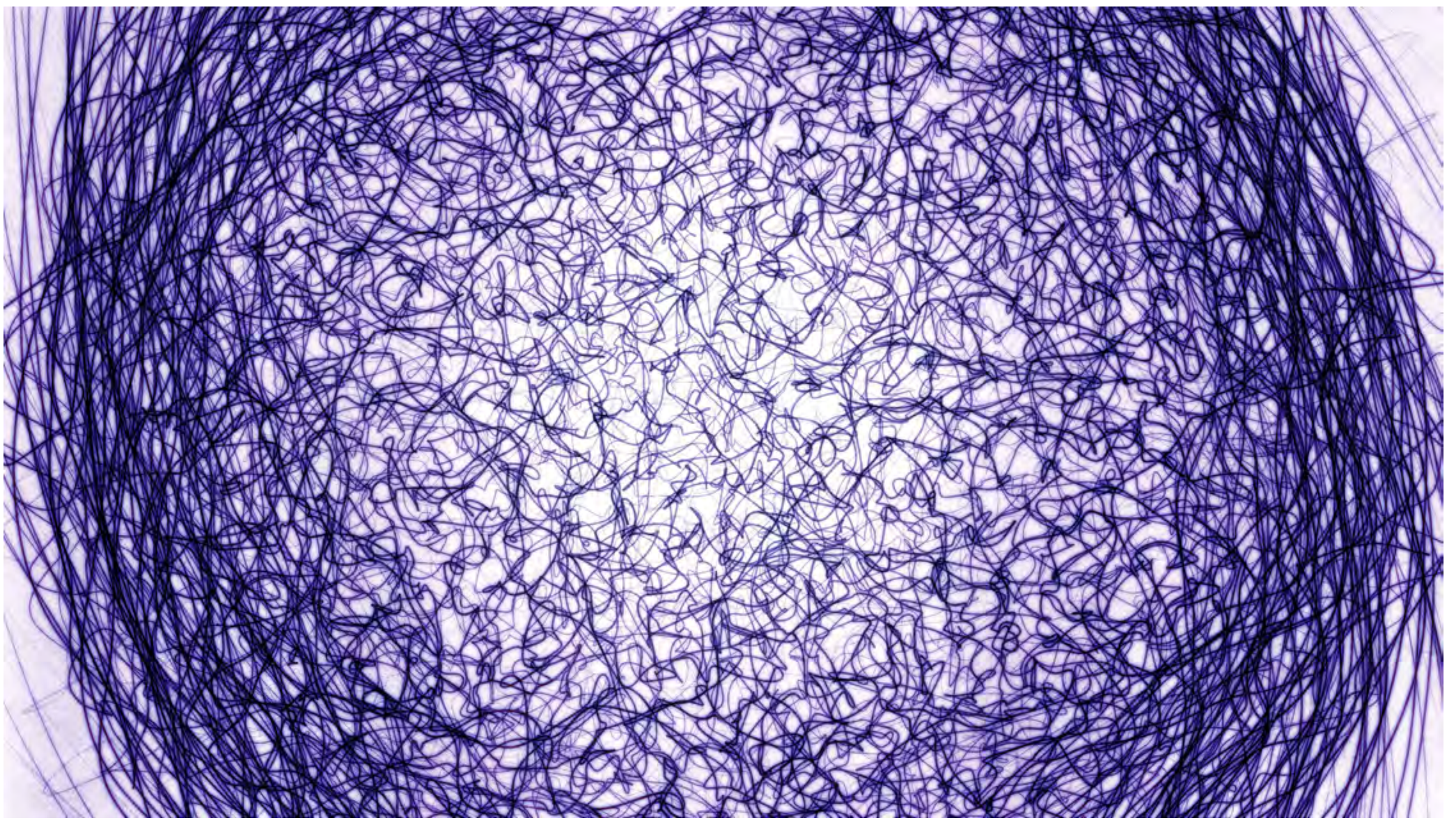
CHIRP

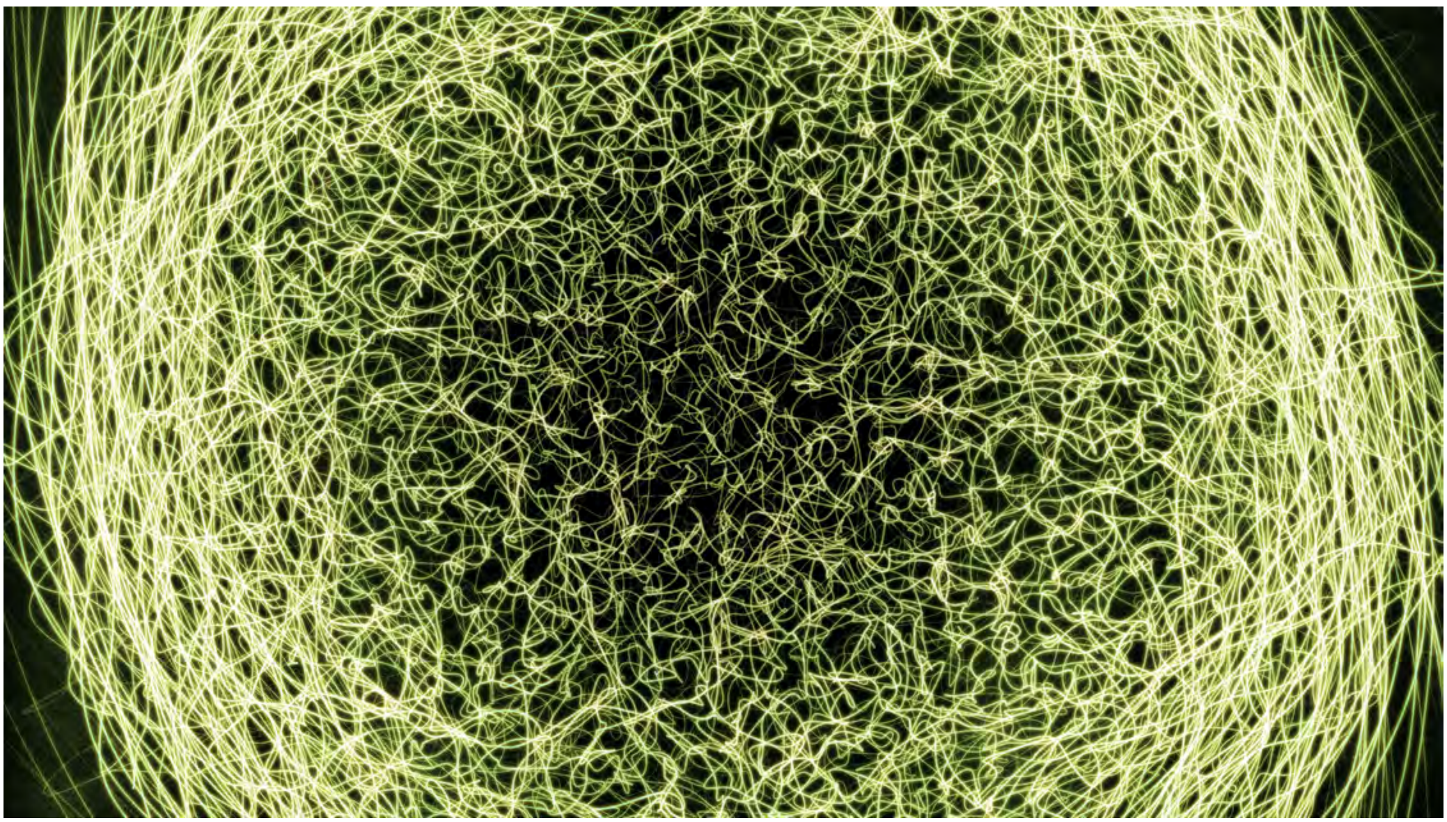
“Chirp” is the result of a particle simulation frozen in time, created by mapping the “chirp” sound of the gravitational waves to various physical forces that escalate into a vortex. It presents the unfiltered data to tell a story by using the familiar appearance of a ballpoint pen scribble. The spatially distributed regular pattern turns into a noise while it transforms memories throughout hidden structural symmetries. The previously interconnected pieces separate to align in a direction and finally form a cohesive purpose. Art has proven to be an extremely effective translator when it comes to communicating difficult concepts in an abstract way to trigger emotions. We often see a mark on the paper that could potentially become something else, such as a line, a drawing or a letter that has meaning. By constraining the marks to forces, the unforgiving quality of the ballpoint pen leaves permanent memories on the paper and acts as a metaphor for stories from the past, describing not only the “what” but also the “how.” The concentric force is without an origin, symbolizing a black hole that we have limited knowledge of. “Chirp” was processed in two different versions, the “positive” and the “negative”, focusing on the sudden disconnection of scale and time by losing the tight connection with the medium.Media Used: The chirp sound of the gravitational wave, recorded by the Laser Interferometer Gravitational-Wave Observatory (LIGO) was used to map a particle simulation driving sampled brushes of ballpoint pens.

Science of the Unseen: Digital Art Perspectives, SIGGRAPH 2016 .

CHIRP



CHIRP



WORD WARS

An interactive installation that downloads current topics from different news outlets in real-time then compares the text and searches for correlations in context. The resulted connections are delivered into an interactive experience where the words are initially hidden, and users decide which path they will follow.

Contemporary Art Museum, Raleigh, NC.

WORD WARS


early
comments
majority
rally
gathered
hardliners
case
turn