6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

PLATE
Product Lifetimes And The Environment

Learning by Transforming: Widening Access to Complex Circular Economy Science using Experimental Design

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Keywords: Materialisation; Visualisation; Experimental design-science education; Biobased recycling processes; Textiles circularity.

Abstract: This paper presents a pilot pedagogical project exploring the potential of experimental design methods to engage students with complex scientific concepts, by focusing on translating these concepts specifically for a public audience. Conducted within the UKRI-funded Textiles Circularity Centre (TCC) at the Royal College of Art, the project tasked design students with designing an experience that can communicate the science of biobased textile recycling, an emerging circular economy process that is complex and typically inaccessible for laypeople. Framed as a process of translation rather than mastery, the project integrated interdisciplinary, multisensory, and speculative design and teaching methods to engage with a range of ways of conceptualizing and communicating complex science to a diverse audience. Students worked closely with scientific researchers, engaging with scientific materials and techniques, including enzymatic recycling and bacterial cellulose production. Through iterative development, the students produced *Catalyst*, a multisensory installation that employs tactile interaction, visual displays, and soundscapes to create an interactive material simulation of biobased recycling. The study identifies three key pedagogical outcomes with potential for application in wider contexts: enhanced technical comprehension, emotional engagement, and learner agency. We discuss the relationship of multimodal design methods to whole-systems thinking and learning. We propose that interdisciplinary, multisensory methods for enhancing complexity-oriented learning and public engagement, and raise possibilities to scale the model to other contexts that involve communication of complex information, as it may be able to activate new forms of learning and public engagement.

Introduction

Art and design teaching offers a valuable contribution to interdisciplinary pedagogy by activating sensory experience. Through creative visualisation and physical materialisation, it enables deeper, more meaningful engagement with complex processes, including those related to futures of sustainable practice in research (Ribul and de la Motte 2018). In this paper we review the process and outcomes of a pilot pedagogical project, which was developed to explore how learners engage with new and complex concepts when the imperative is not simply to understand the concepts, but ultimately to communicate them to others through created experiences. This pilot was carried out within the Royal College of Art (RCA)'s UKRI-funded Textiles Circularity Centre (TCC), a project investigating the transition to a circular textile economy for the UK fashion industry. In the pilot, design students were tasked with creating an experiential artwork for a public audience that communicates the workings of biobased textile recycling, as a way of engaging the public with sustainable textile futures. Building on existing research that confirms the potential of advanced visualisation and materialisation methods to enhance learning (Klerkx et al., 2014) the pilot demonstrates the value of experimental design practices for interdisciplinary learning, where the imperative is not just to learn for oneself, but to translate concepts to mixed audiences.

Advances in biotech have enabled a novel category of circular textiles recycling, involving complex bio-based processes that transform biowaste into new materials (Ribul et al. 2021). Making the public aware of how such processes work, as well as why they are innovative and valuable, has an impact on new product adoption and perception of brands who use such practices (Braga et al., 2024). Understanding parts of the processes themselves is important, as consumers tend to respond more favorably to changes when they can be assimilated within existing competencies (O'Keefe et al. 2016). This presents particular challenges when the processes involved in biobased recycling are highly complex and typically inaccessible in that they are confined to a laboratory setting. These factors are barriers to public understanding and interest, and represent a missed opportunity to prime the public to adopt new modes of decision-making in relation to fashion.

Having access to a wide range of interdisciplinary expertise in creative experimentation at the RCA, our response was to consider how experimental design methods could be tested as a mode of learning new concepts. TCC and the RCA's Materials Science Research Centre (MSRC) commissioned and supported students in creating public-facing designed experiences, where the outcome was designed to engage the public with the bio-based materials recycling processes in a way that would be engaging as well as faithful to the science. Our broader intention was to evaluate the effectiveness of framing the knowledge gap (students had no previous knowledge of these scientific processes) as a design challenge, where the ultimate goal was to make the information legible and interesting to others. We aimed furthermore to explore the applicability of this framing and methodological approach beyond the formal educational environment.

Background

Experiential design, immersion and complexity education

There is a consistent suggestion across research that immersive experiences, engaging both digital and analogue elements, can promote change in perspective and decision-making by triggering motivational processes that engage 'thinking-through' versus 'thinking-of' (Wouters et al. 2013). Immersive experiences, in this context, refer to environments or activities—physical, digital, or hybrid—that fully absorb participants' attention and invite creative improvisation and active engagement with the world or a simulated system. Rather than merely observing, participants are situated within a responsive environment that encourages exploration, experimentation, and reflexivity. This definition spans virtual reality (VR), augmented reality (AR), physical prototyping, and performative engagements where the process of interaction is as critical as the content (Dourish 2001; Murray 1997; Bolter and Grusin 1999; Gibbons 2018).

With respect to socio-environmental issues, immersive experience has real impact for education and communication on issues related to sustainability (Mnih et al., 2015; Verburg et al. 2016; Doganca Kucuk and Saysel 2018). Furthermore, immersive experiences that involve building or making, including 3D visualisation and active interaction with materials and content, enhance learning experiences and lead to deeper and more comprehensive understanding (Lau and Lee 2015; Angel et al. 2015; Jowsey and Aguayo 2017). Examples include Aalto University's New Silk project, where collaborative making across science, design, and art generated new knowledge through experimentation (Niinimäki, Groth, and Kääriäinen 2018). Similarly, the ChemArts programme also at Aalto University fosters interdisciplinary exploration of cellulosic and biomaterials, inspiring designers and advancing research (Kataya and Kääriäinen 2018; Kääriäinen et al. 2020).

Multisensory Experience, Emotion and Scale in Learning Complex Concepts

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Conceptual frameworks focused on the visual ('visualisation') tend to dominate engagement strategies and have the widest body of associated research validating their effectiveness in teaching and learning. As a result, 'visualisation' is often used in the literature as a catch-all term where the visual is a key element rather than the only element. Video, animation and generative data visualisations are acknowledged as important education tools in the context of complex science, enabling exciting forms of visual storytelling, and introducing elements of temporality and dynamism which may underline how components are in relation between each other (Curtis and Lue 2015).

Using multiple sensory modes are found to be valuable in engaging learners with complex concepts, particularly when communicating different levels of systemic interaction simultaneously (Ouhaichi et al., 2024). This was an important starting point for our pilot. A dimension of particular interest for us was the emotional impact of material experience and its relation to learning, where some research suggests that learners connect to concepts more effectively and with greater enjoyment when they engage both physically and emotionally with tangible objects or materials (Harley et al. 2016). This is not fully understood, but there appears to be a positive connection between haptics (touch), emotional experience, and behaviour change associated with new knowledge. This follows consumer research where the human 'need for touch' has been identified in marketing and consumer behaviour, the phrase used to describe a common trait where haptic information is highly valued and influential in decision-making (Peck and Childers 2003; Yazdanparast and Spears 2012).

Sound has a particular impact on learning in complex scenarios, where researchers have found fruitful conceptual links that enable them to use soundscapes to communicate variability of landscapes and biodiversity, for example, and to use acoustic parameters to help users assess complex variables of real complex environments (Maffei et al. 2016). There is a growing body of research concerning the capacity for sonic experience to be used in consumer-facing projects related to soil biodiversity, ocean reef health, and other environmental and systemic concepts that are not simple to communicate in language (Hayes & Stein, 2018). Finally, working in multiple sensorial registers enables the learning process to engage with multiple scales of reference, including spatial and temporal. This is a particular benefit in relation to scientific and systemic problem spaces, where most impacts and interactions are usefully understood as connected across multiple scales (Ribul and de la Motte 2018).

Method

Our approach combined design-led and science-led pedagogical methods. Students were tasked with creating an in-person experience to engage lay audiences with biobased recycling processes. The brief framed this as a process of 'translation,' requiring students to explore both analogue and digital design methods and to engage directly with the scientific processes through guided research and participation in TCC activities over six months. They received a consumables budget, and the final selected work, exhibited in the TCC's public Regenerative Fashion Hub, received a prize. A core principle of the brief was scientific correspondence—ensuring accuracy—balanced with the need to create an emotionally and intellectually engaging audience experience. While the work could abstract or simplify the science for accessibility, it could not misrepresent it.

The project began with a briefing and workshop where the TCC research team and interdisciplinary partners presented their expertise. Students then received tutorials on both design and scientific elements before project proposals were reviewed by TCC members and associates. Once selected, the student team participated in weekly tutorials with TCC researchers and exhibition designer Claudio Quintana, receiving design critiques and feedback from experts at key stages of development (see Figure 1).

Science Teaching & Research Methods

The structure of the learning process required that students first demystify the science for themselves through interdisciplinary research and with the support of the TCC team, and then to translate the science for laypeople through design, with the support of tutors in Information Experience Design. Students were embedded within the TCC project for the duration of their work, participating in, for example, an interdisciplinary seminar where Simon McQueen-Mason presented a novel biobased recycling concept in which post-consumer textiles can be deconstructed through the use of an enzymatic digestion to produce sugars that can then be fermented by bacteria leading to a biological repolymerisation (Lanot et al., 2025). The students were then given access to a video illustrating how the overall process can be carried out in a laboratory setting and how the structure of the material can be analysed using a Scanning Electron Microscope. The seminar, videos, scientific materials and meetings provided the means for integrating scientific principles and understanding into the design of the collaboration.

Based on the literature review conducted on design-led and science-led case studies of materials' visualisation of scientific processes, a scalar paradigm and a matrix tool was proposed to the students to approach the development of the project (see Figure 2). The scalar paradigm entailed: the macro scale, the human scale and the micro scale. The opportunity for the students to receive feedback, regular reviews and to discuss directly with the research team has played a pivotal role in first developing their understanding of the stages underlying the scientific principles of the complex biobased recycling process of the TCC, namely: cellulose-based waste feedstocks such as post-consumer textiles (cotton or lyocell) and straw to produce a liquid mixture using enzymes which then feeds bacteria to create cellulose strands that self-form into sheets, as a feedstock for circular textile production (Lanot et al, 2025).

Experimental Art & Design Methods

The learning and teaching methods arising from experimental design focused on using speculative and postdigital practices to deepen engagement with the materials and concepts at hand, and to widen possibilities for engaging audiences in novel formats. Speculative practices are enabled by modes of thinking beyond the given parameters, involving "what if" questions and scenarios. In the essay *"Treading Lightly in a World of Many Worlds",* design team Dunne and Raby muse upon how "[o]ur senses edit what is out there, as do those of every creature. Some life forms live in worlds where the human-body shape is meaningless. We appear more like clouds, atmospheres or energy fields" (2023). The idea that everything we encounter is filtered through our particular biology is useful in reframing how we might communicate with others, and indeed what we might communicate. In tutorials and through the design process, we challenged the students to engage in different speculative practices designed to reframe the scientific processes and engage with these from different possible perspectives, including nonhuman materials and micro-scale interactions.

Postdigital methods deliberately blend analog and digital, technological and biological, resisting binary thinking and technological determinism (Kamenarac, 2024). This approach disrupts boundaries between formal and informal learning, shifting 'unreflexive certainties into reflexive uncertainties' and encouraging learners to explore multiple futures (Jandric et al., 2018). Guided by this, students combined digital and analog modes and crossed disciplinary boundaries without conforming to traditional discourse. This aligns with Jandric and Ford's concept of postdigital ecopedagogies—educational practices that embrace the complexity and interdependence of human, machine, and nonhuman ecosystems (2022). These recent revisions of broader interdisciplinary pedagogic practice are conversant with whole-systems thinking and change, as well as with the ecological sciences, particularly landscape ecology and Earth system science.

With these conceptual guides, the experimentation process was governed by methodologies from experimental design practice, including embedded research processes, informed speculation, iterative audience and materials testing, and collaborative/connected praxis. Early ideation processes led to an agreement that the work should entail three elements: learning through playful interaction; an interplay between human and nano-scales; and the engagement of the layperson as a stakeholder in the recycling process. The final outcome produced from within this framework was a piece titled *Catalyst* (2022) (Figure 4), wherein the audience becomes the catalyst in the transformation of textile waste into materials in biobased recycling. It includes a tactile sculpture (a rotating drum to be operated by visitors), a visual display illustrating the production of bacterial cellulose (Figure 5), and an evolving soundscape linked to these. Together, the three elements form a narrative, wherein publics are invited to play the role of the 'catalyst' in biotech processes creating a more sustainable textile industry.

Discussion

We understand the value of using experimental design methods as teaching tools in a scientific context to arise in three areas: technical comprehension, emotional engagement, and agency.

Technical Comprehension

By engaging with the science itself, including material experimentation with bacterial cellulose, students were able to contextualise the technical dimensions of their creative materialisation against the real technical dimensions of the recycling process. The contributions of the scientific stakeholders in the research phase involved making these technical concepts accessible for students through access to materials, processes and documentation, from low-fi sketches to high-quality digital imagery. Students used shared materials throughout the pilot to develop their own translations in visual and other sensorial formats, in every case recontextualising the processes iteratively to understand them in different contexts.

Emotional Engagement

Emotional engagement was of interest to both the designers and the researchers, as the design process and the intended emotional content of the work itself, ie. the hoped-for emotional impact on audiences who might engage with it, are both important to the brief. This informed the processes and outcomes in several ways. Given sound's established emotional impact (Comstock & Hocks 2016), students used it to foster empathy with micro-scale entities, enhancing audience connection. The designers' decision to include the audience as the 'catalyst' of the piece (and the implicit commentary that transformation depends upon an investment of energy by people) was another decision that reflected a focus on engaging audiences emotionally with the piece, involving them directly in the outcome. Immersive experiences, including visualisations, sound and installation, can effectively induce mood states of awe, which has interesting potential for application to experience design (Chirico et al 2016) and is noted by the students in their own experience in this project.

Agency

Students separated into disciplines are often attuned to division in a way that keeps them "in a single lane"; for example, a belief that scientific research is highly complex, abstract, distant, and owned by a group of specialists; students of science might say the same of the field of experimental art. This project intentionally broke disciplinary silos, positioning students as translators rather than specialists, shifting focus from mastery to communication. This not only levels certain hierarchies, but also refocuses effort from the self—attention on one's own success or failure in mastering new material—to the community—attention on how this might be useful or interesting to others, and have benefits beyond the self. In practical terms, this means that when encountering information, the student is obliged to think about what information will be most relevant and interesting for someone else, what type of narrative will be most suitable for different audiences, and how they might empower others to engage even when mastery or certainty is not likely. The final piece likewise engages learners (in this case, the audience) in activating their own learning process by physically engaging as an active part of the process, rather than attuning to a high level of specialist and possibly alienating scientific detail. A paper associated with the audience reactions by the TCC project team is under review elsewhere (Jewitt et al).

Conclusions

The pilot study presented in this paper has evaluated and identified clear potential for an interdisciplinary model of translation-focused learning, with the simultaneous goal of widening access to complex circular economy science of textile recycling in a public-facing context. Within this study, the students metabolised the complex science behind biobased recycling–supported by constant interactions with the interdisciplinary TCC team–and translated this complex process in a multi-sensory installation to allow laypeople to interactively navigate the process. The project benefitted from embracing the three scales of representation at the cross-section of design and science: macro-, human- and micro-scale and from the adoption of multimedia and multi-sensory input. This supported a cognitive and emotional experience that facilitated understanding of complex processes for the students, as a valuable learning process. The methodologies and insights resulting from this work can be scaled and adapted to other contexts in complexity-oriented education, where language- and text-based modes are less effective. This has special relevance for institutions, courses and subjects that benefit from interdisciplinary and whole-systems approaches; the findings also have potential for application by those interested in emotional and sensory learning modes applied to complex topics, in a variety of educational contexts including public engagement.

Acknowledgments

The work was funded by the Engineering and Physical Sciences Research Council (EP/V011766/11) National Interdisciplinary Circular Economy Research (NICER) programme for the UKRI Interdisciplinary Circular Economy Centre for Textiles: Circular Bioeconomy for Textile Materials.

Data availability statement

The original data presented in the study is openly available in the publicly accessible Royal College of Art repository: https://researchonline.rca.ac.uk/5662/.

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Figures

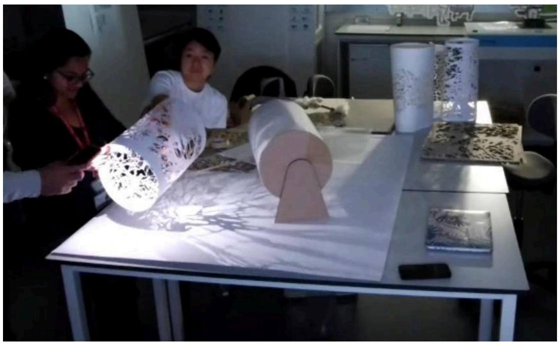

Figure 1. One of the tutorials with the selected team investigating the option of inserting a light feature in the drum.

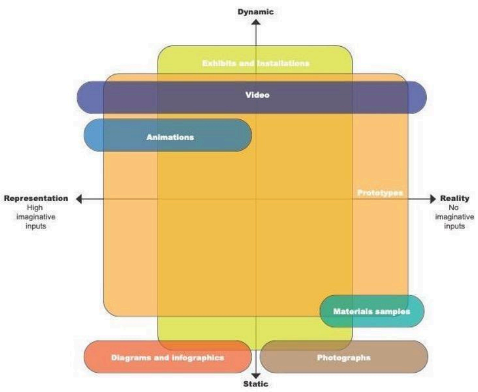

Figure 2. The visualisation and materialisation matrix suggests how different methods could be placed. For example, prototypes can be dynamic or statics and could have a real function or they could be diegetic objects, hence the category 'prototypes' expands in each quadrant of the matrix. On the other hand, photographs are statics and often offer an 'edited' portrayal of the reality hence they occupy the 'static-reality' quadrant.

Figure 3. The *Catalyst* installation close up.

Figure 4. The C*atalyst* in the exhibition space.

Figure 5. One of the stills from the video which portrayed the journey from the nano-scale to the materialisation of the bacterial cellulose into a textile-like material.