University of Kent

Kent Academic Repository

Czech, Elaine, Tabbaa, Luma, Li, Xiang, Ppali, Sophia, Cullen, Yvonne Mary, Ang, Chee Siang, Verma, Himanshu and Covaci, Alexandra (2026) *Reclaiming creative exploration: An in situ study to support process-based learning through digital making in low socioeconomic schools.* In: IDC '26: Proceedings of the 25th Annual ACM Interaction Design and Children Conference. . pp. 491-506. Association for Computing Machinery ISBN 979-8-4007-2283-7.

Downloaded from

https://kar.kent.ac.uk/115971/ The University of Kent's Academic Repository KAR

The version of record is available from

https://doi.org/10.1145/3773077.3806129

This document version

Publisher pdf

DOI for this version

Licence for this version

CC BY (Attribution)

Additional information

Versions of research works

Versions of Record

If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

Author Accepted Manuscripts

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) 'Title of article'. To be published in ***Title of Journal*** , Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

Enquiries

If you have questions about this document contact ResearchSupport@kent.ac.uk. Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies).

Reclaiming Creative Exploration: An In Situ Study to Support Process-based Learning Through Digital Making in Low Socioeconomic Schools

Elaine Czech
University of Kent
Canterbury, United Kingdom
elaineczech@gmail.com

Luma Tabbaa
School of Engineering, Mathematics & Physics
University of Kent
Canterbury, Kent, United Kingdom
L.A.Tabbaa@kent.ac.uk

Xiang Li
University of Kent
Canterbury, United Kingdom
xl273@kent.ac.uk

Sophia Ppali
CYENS Centre of Excellence
Nicosia, Cyprus
s.ppali@cyens.org.cy

Yvonne Mary Cullen
University of Kent
Canterbury, United Kingdom
yvecullen@gmail.com

Chee Siang Ang
School of Computing
University of Kent
Canterbury, United Kingdom
Kent and Medway Medical School
Canterbury, United Kingdom
Imperial College London
London, United Kingdom
c.s.ang@kent.ac.uk

Himanshu Verma
Knowledge and Intelligence Design
Delft University of Technology
Delft, Netherlands
H.Verma@tudelft.nl

Alexandra Covaci
School of Engineering
University of Kent
Canterbury, Kent, United Kingdom
a.covaci@kent.ac.uk

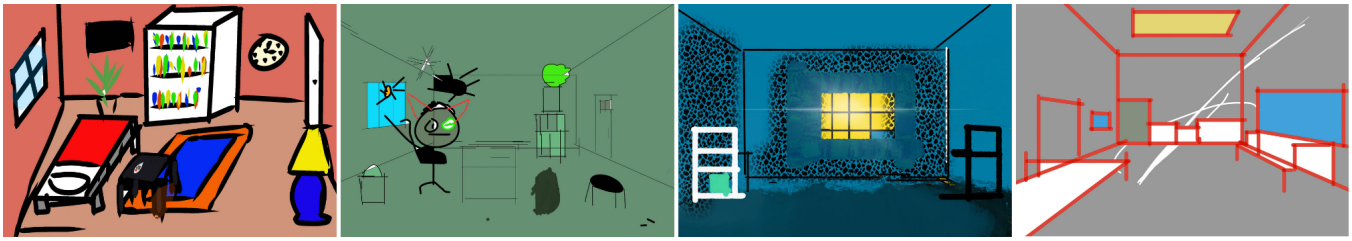
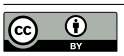


Figure 1: Four examples of Year 7 pupils' visualisations of *fair prisons* created during the School B history unit on crime and punishment. Pupils developed designs through sketching and digital making, exploring how space, light, and everyday amenities could make punishment feel fair.

Abstract

Secondary school systems often reward predictable, mark-bearing performance, making experimentation feel risky, especially in under-resourced contexts, where time, attention, and materials are tightly managed. We report on an exploratory case study of a charity-led digital arts programme delivered in two low-socioeconomic secondary schools in which immersive (i.e., Virtual Reality) and non-immersive (i.e., tablet-based) digital tools were introduced into Year 7 (400+ pupils, typically aged 11–12) curriculum. Through thematic analysis of the lesson observation notes and student surveys, we show that pupils take more creative risks, value exploration, iterate more, and increasingly learn through and with peers. We characterise shifts in classroom ecology, including shared talk, turn-taking, micro-tutorials, and practices of care and repair that help sustain learning-in-process. Finally, we analyse the breakdowns and trade-offs of deploying off-the-shelf creative technologies in low-resource school routines, and derive deployment lessons for resilient, bottom-up creative technology curricula that fit everyday classrooms.



This work is licensed under a Creative Commons Attribution 4.0 International License.
IDC '26, Brighton, United Kingdom
© 2026 Copyright held by the owner/author(s).
ACM ISBN 979-8-4007-2283-7/26/06
https://doi.org/10.1145/3773077.3806129

ACM Reference Format:
Elaine Czech, Luma Tabbaa, Xiang Li, Sophia Ppali, Yvonne Mary Cullen, Chee Siang Ang, Himanshu Verma, and Alexandra Covaci. 2026. Reclaiming Creative Exploration: An In Situ Study to Support Process-based Learning Through Digital Making in Low Socioeconomic Schools. In *Proceedings of the 25th Interaction Design and Children Conference (IDC '26), June 22–25, 2026, Brighton, United Kingdom.* ACM, New York, NY, USA, 16 pages. https://doi.org/10.1145/3773077.3806129

1 Introduction

Education in secondary schools (typically serving children aged between 11 and 16 years) is frequently organised around institutionally certified attainment, most commonly evidenced through time-bounded summative assessments that tend to assess Low-Order Thinking (LOT) skills (i.e., remembering, understanding, and applying given information) [40]. While such assessment offers administrative consistency and comparability, it also powerfully shapes what pupils come to see as worth doing: learners are incentivised to optimise for marks by playing it *safe*, rehearsing what is examinable, and concentrating effort on subjects positioned as 'more important' or more readily counted, benchmarked, and inspected [5, 12, 35, 65]. This strategisation may increase pupil performance against measured outcomes, yet it can suppress the development of Higher-Order Thinking (HOT) skills development (i.e., problem-solving, creativity, self-regulation, etc.) that modern pedagogical frameworks identify as essential [26, 37, 52]. These competencies are not only educationally valuable within secondary schooling; they are foundational for progression to university life, employability, and civic participation in technology-enabled societies [24, 39, 70]. Such narrow approaches in assessment can also make open-ended exploration feel risky or irrational [27], intensify pupils' anxiety around grades and schooling [93], and distort how pupils interpret and use feedback in practice [13]. As such, there is a need to shift away from regimes that privilege predictable, mark-bearing performance toward constructionist pedagogical approaches that cultivate iterative inquiry, reflective judgement, and self-regulation—particularly in creative disciplines where competence is constituted through iterative making, critique, and reflection [1, 57, 58, 69, 73, 74].

Human–Computer Interaction (HCI) research has examined a wide range of ways in which digital tools can support process-based learning [17, 22, 31, 33, 45]. Having technology in the classroom serve as "*objects to think with*" [73], helps form part of the infrastructure for widening pupils' prospects, employment rates, and economic participation [6]. Despite efforts to merge makerspaces and constructionist pedagogy into formal classrooms [73, 76–78, 86], there continues to be a push for formal assessments despite this going against the ethos of this type of learning [38]. As such, many interventions are still designed, implemented, and evaluated to mirror traditional approaches: emphasise pre-specified tasks, demonstrable competencies, and polished outputs that are easy to assess, rather than sustaining open-ended inquiry, iteration, and learning-in-process over time [51, 79, 95]. Particularly in under-resourced schools, constraints on time, staffing, infrastructure, and teacher capacity then make adopting and sustaining technologies that support process-based learning more risky [42, 82, 92].

This paper presents an in situ study that explores how immersive (e.g., Virtual Reality (VR)) and non-immersive technologies (e.g., tablet) using mainstream apps (e.g., OpenBrush (VR), Scaniverse (tablet)) might enable the development of pupils' HOT skills through a process-based, exploratory learning, inspired by creative art practices — placing less emphasis on final evaluation and greater emphasis on learning as it unfolds through exploration, iteration, and reflection. We report on a charity-led digital arts programme delivered by volunteering local professional digital artists in collaboration with school teachers in Year 7 pupils (typically aged 11–12). Our study is situated in two secondary schools in the coastal region of England, United Kingdom (UK), in low-socioeconomic communities with a high proportion of pupils with Special Educational Needs & Disabilities (SEND) and below-average reading skills. Drawing on observational data and pupil surveys, we analyse how pupils and teachers appropriated digital tools, identifying the breakdowns and classroom reconfigurations necessary to sustain process-first learning. We add infrastructural considerations to Scheepmaker et al.'s socio-material toolkit [82] for integrating technology into schools by translating our insights from in-situ deployment for resilient, bottom-up curricula that can withstand the constraints that low-socioeconomic communities face. In doing so, we address the following research questions:

- **RQ1:** How does process-based technology-mediated creative learning shape the development of pupils' HOT skills?
- **RQ2:** What classroom-ecology changes emerge when immersive and non-immersive digital tools are used in collaborative creative pedagogies?
- **RQ3:** What breakdowns, constraints, and trade-offs condition the deployability of a bottom-up, off-the-shelf creative technology curriculum in low-socioeconomic secondary schools, and what lessons learned from deployment can help with facilitating resilient implementation?

2 Related Work and Background

2.1 The Schools' Systematic Fixation on Measurable Outcomes

The importance of developing HOT skills, and what some research refers to as "*21st century skills*", has been identified as a critical priority for enhancing secondary school education. Such skills include problem-solving, meta-cognition, critical thinking, teamwork, and innovation, which are foundational to future citizenship and participation in technology-empowered dynamic social and work environments [26, 37, 52]. However, the reality is far from this; learning in schools is frequently operationalised as institutionally certified attainment, most commonly evidenced by time-bounded summative assessments [34, 48]. While this outcome-centric measurement regimen affords administrative clarity and comparability, it can miss substantial opportunities for pupil learning by exerting strong "*washback*" effects on what pupils perceive as worth doing. Specifically, it rationally encourages pupils' grade-oriented optimisation—prioritising predictability, rehearsing examinable forms, and allocating effort to mark-bearing tasks—thereby narrowing curricular engagement and constraining pupils' willingness to explore diverse topics, generate ideas, or pursue exploratory lines of inquiry that are unlikely to translate into examinable outputs [27]. Furthermore, such emphasis on the end grade can intensify pupils' anxiety, which is linked to poorer educational performance,

disrupted learning behaviours [93], and distort the function of feedback comprehension [13]. Such pressure can be particularly detrimental to pupils' well-being during secondary school, a period already characterised by heightened stress and adjustment demands associated with the transition from primary education [53].

These challenges are further exacerbated within creative subjects (i.e., arts, design, music, history, drama, etc.), which are often squeezed in favour of subjects that are deemed 'more important' or can be easily counted, benchmarked and inspected [5, 12, 35, 65]. Yet, the epistemic character of creative learning does not align with traditional outcome-centric logic; competence is commonly developed through practice — pupils learn by iteratively exploring possibilities, producing and revising work, and making their reasoning accountable through critique and reflection - so pedagogies that foreground experimentation and feedback-rich cycles are not ancillary but constitutive of disciplinary learning [57]. Specifically, research found that process-centred learning, iterative inquiry, reflection, and self-regulated learning processes can better surface critical thinking and meaning-making than reproduction-oriented tasks [11, 58, 69].

As a direct contrast to traditional pedagogy, constructivists believe that learning comes about when a child actively 'constructs' through experience a means of understanding the world [1, 74]. Among those advocating for constructivist pedagogy, Seymour Papert promotes constructionism, that knowledge is formed and transformed in-situ and that technology can serve as a means for developing tangible artefacts which evidence one's learning [1, 73]. Two of the most well-known constructionist digital tools are Turtle Graphics and Scratch; both were built for learning and have proven to be successful. Researchers recently have explored how other technologies (such as extended reality) can potentially be used for facilitating constructivist learning [30, 62]. As Smith and Tissenbaum [84] noted, these ubiquitous tools are useful for promoting hands-on learning in areas where standard makerspaces and devices are not accessible. However, it seems that these technologies, as constructionist objects, have rarely been used to help students grasp concepts beyond computational thinking. Instead, for creative subjects, topics like history are presented as built environments for students to immerse themselves in [3]. Additionally, digital art creation is sometimes viewed as distinct from physical art creation, with educators valuing one over the other [4] (although unique examples like [68] demonstrate some skill transferability between digital and physical mediums). Savin-Baden et al. [81] evidenced the benefits already seen in higher education when more interactive and immersive technologies are used to "*engage students who are less responsive to conventional teaching methods*" and "*extend learning opportunities to students in remote or underserved areas.*" However, examples of incorporating augmented, virtual and mixed reality for collaborative learning of creative subjects, especially within social sciences, with secondary students are rare [83]. With this paper, we aim to explore this space by introducing secondary students to constructivist learning through interactive and immersive technologies in creative subjects.

2.2 The Reality of Technology-Centred Deployment in Schools

Within the HCI research community, a substantial body of work has examined how digital technologies could support pupil learning in schools across various subjects, including literacy (e.g., Generative Artificial Intelligence (Gen-AI) to support writing projects [33]), mathematics learning (e.g., tablet-based Augmented Reality (AR) interactive maths activities [45]), computational thinking (e.g., smartphone-based voice-guided storytelling app [22]), arts (e.g., pottery-making using VR [31]), and culturally-oriented learning activities that support history education (e.g., interactive whiteboards and tabletops for museum-inspired activities [17]). Such solutions often support pre-specified tasks, demonstrable competencies, and outputs that are readily displayable and assessable, rather than sustaining open-ended inquiry over time (a tension also documented in HCI-adjacent making/design-in-school work as classroom 'making' becomes oriented toward functional, finished deliverables) [51, 79, 95]. While much of the constructionist research has examined how to shift from outcome-based to more process-based approaches [73, 76–78, 86], much of this work is still focused on promoting computational thinking rather than the creative learning that can play out when digital tools are woven into the fabric of lessons. This work aims to fill this gap by providing empirical results which illustrate how technology assists children's process thinking when the focus is less on the digital skills.

A further, and often underestimated, barrier to integrating educational technologies is deployability: as HCI researchers have noted, individually tailored systems and bespoke installations evaluated under comparatively controlled conditions are not sustainable with the logistical, material, and methodological constraints that shape everyday school routines [25, 82, 87, 92]. This gap becomes especially consequential in under-resourced and low-socioeconomic settings, where schools prioritise essentials for accreditation over 'extras' such as digitally supported learning. The lack of digital literacy among teachers is a well-documented barrier to the deployment of technologies, particularly newer technologies such as AR and VR [51]. Without adequate support and technology champions to ease technology integration into the classroom [36], this can hinder a teacher's ability to manage their classroom, sequence activities, and adapt to facilitative, pupil-centred pedagogies [42]. Scheepmaker et al. [82] suggest with their toolkit for teachers that collaboration with maker educators (those affiliated with a fixed makerspace) would be a good avenue for mitigating the burden placed on educators. However, as we explore in this paper, there are benefits to 'portable' maker educators.

2.3 Contextualising The Research: Schools in Low Socio-Economic Areas & Coastal Communities in The UK

In the UK, low-socioeconomic areas are defined using Indices of Deprivation (IoD), which capture compounded disadvantage across the following domains: low household income, lack of employment, weak educational attainment and skills development, poor physical and mental health outcomes, reduced quality of life, high crime rates, restricted access to adequate housing and essential services, and poorer quality local environments (both indoor and outdoor)

[61]. Coastal (sea-facing) communities within the UK are commonly characterised as low-socioeconomic areas; specifically, two in every three coastal towns are classified as high-income deprivation areas, with high rates of major disease, and poor education levels [72].

In the context of school education, pupils from low-socioeconomic backgrounds struggle to meet expected standards in writing and mathematics; 53% of disadvantaged pupils are below expected literacy attainment levels, compared with 31% of other pupils, and the disadvantage gap in reading was 17 percentage points [20]. Of course, this means that such schools often prioritise "core" subjects such as English and mathematics, leaving little or no curricular time and provision for creative and vocational subjects [67]. Furthermore, special learning and support needs are strongly associated with low social and financial status and are therefore concentrated in many low-socioeconomic areas. In fact, 43.8% of pupils receiving an Education, Health, and Care Plan (EHCP) in England are from low-income households [21]. Therefore, there is an immense need for pedagogical responses that cultivate pupils' interest, sustain meaningful learning for all (i.e., inclusive solutions), consolidate knowledge, and build skills within the constraints of everyday classrooms.

Access to digital technology also remains socio-economically stratified in the UK. Ofcom[1] estimates that 17% of pupils lack access to a technological device, rising to 27% among the most financially vulnerable households [71]. These disparities carry significant consequences, as digital literacy is strongly associated with higher employment rates and economic participation [6]. Accordingly, digital competence can no longer be regarded as an optional enrichment: sustained exposure to digital technologies and the deliberate development of pupils' technical skills are essential foundations for future employability and inclusion in the modern economy across most sectors, including health and social care [88], finance [91], manufacturing [46], public service [60], and construction [18], just to name a few. Furthermore, limited exposure to digital technologies can constrain pupils' ability to develop interest in, and a sense of belonging to, technology-intensive domains—narrowing their awareness of tech-centred future career entails and reducing the likelihood that they pursue technology-centred pathways. This socio-economic skew is evident in the UK: only 19% of workers in the tech sector are from working-class backgrounds (compared with 33.3% across other sectors) [66]. Therefore, it is essential to support schools—particularly those serving low-socioeconomic communities—to identify viable and practical approaches that provide equitable, ongoing opportunities for pupils to engage meaningfully with digital technologies, building foundational technical competence while widening horizons and enabling fair participation in technology-mediated futures.

3 Methods

3.1 Methodological Overview & Positionality of Research Partners

Methodologically, the research is an in situ, naturalistic exploratory study of how a charity-led digital arts programme is taken up in everyday school practice, with our analysis explicitly attending to these contextual conditions when interpreting classroom events. "*In situ*" approaches in research are recognised as a "*paradigm shift*" in which HCI researchers leave the safety and security of controlled lab environments to better understand how interventions, technologies, designs, or approaches would withhold real life conditions [15]. To this end, we adopted an embedded, participatory qualitative case study design to examine what happens when subject delivery shifts from a predominantly outcome-oriented to a more process-centred approach, supported by digital arts practices involving both immersive and non-immersive technologies. This orientation draws on Participatory Design (PD), a well-established approach that emphasises the active involvement of relevant stakeholders in co-design processes [75]. PD has been used productively across a range of contexts, including teaching and learning [63, 68], and children-centred research [10, 28].

As such, we partnered with a local arts charity[2] (hereafter, the *Charity Partner*). The Charity was founded in 2015, within a low-socioeconomic area, by a digital composer, a visual artist and educator. The Charity aims to up-skill the next generation through projects that enable local people to access digital art-making tools to create and share their stories. For this project, the Charity Partner co-designed curriculum-aligned, technology-enabled learning activities for Year 7 pupils (ages 11–12) with two secondary schools located in a low-socioeconomic coastal local authority in England. The delivery of the curriculum units was led by the Charity volunteers, who are local professional digital artists (hereafter, *Art Facilitators*) in close collaboration with Year 7 teachers. In terms of planning and curriculum design, we (as academic researchers) were involved in meetings between Charity Partners and school decision makers and teachers, however, much of the decisions that shaped the intervention were driven by the school needs, timetables, and subject-specific priorities, as well as the Charity Partner's financial constraints, access to technologies, and what would draw on the existing expertise and backgrounds of the volunteering Art Facilitators. As such, the Charity Partner led on the resourcing technologies, logistical arrangements, sourcing of Art Facilitators, and any other administrative work required to deliver the intervention successfully. The schools, on the other hand, identified the subjects, specific timetable sessions, and the teachers who will collaborate with the Art Facilitators to co-deliver these sessions. Considering the schools have a high proportion of pupils with SEND and below-average reading scores, and given that the Art Facilitators were not specialists in adapting art-based activities for pupils with SEND, the lesson plans were shaped and iteratively refined through teachers' expertise and feedback during the co-design process to support the full range of learners in mainstream classroom settings.

Our role as academic researchers was primarily for data collection and analysis purposes. Specifically, one researcher, who is an expert in multi-disciplinary HCI research, provided academic oversight of the research process and acted as the main academic point of contact. In addition, one researcher (researcher in Drama (i.e., participatory community theatre) who also has 15 years of prior experience as an English & Drama secondary school teacher) was dedicated to document meeting minutes (i.e., between the Charity Partner, schools, and researchers), document observational notes

[1] https://www.ofcom.org.uk

[2] https://www.electricmedway.org

in all classroom activities across both schools, and administer an end-of-term pupil survey. Finally, the remaining members of the research team (HCI (n=3) and creative practice (n=3)) were involved in the data analysis and synthesis that followed data collection.

3.2 Ethics

The study design and data collection method was approved by the Central Research Ethics Advisory Group (CREAG) at the University of Kent (Ref. CREAG059-04-25). As the Charity Partner and schools identified the school year and curriculum subjects that were appropriate (and most in need of the intervention). As such, Year 7 (11–12 years) cohorts undertaking the arts subject in School A, history in School B, and one mixed-age SEND class in School B were identified as suitable for participation. All students were considered to participate in this intervention regardless on their abilities and skills. This is to ensure that the intervention was inclusive for all and all Year 7 students undertaking these subjects had an equal opportunity to experiment with technologies. The process of briefing the parents about the study aims, methods, data collection, and duration was all handled by the schools' relevant administrative teams and in support of the Charity Partner. Parent consents and pupil assents were collected by the Charity Partner. Only those who provided consent attended these sessions. Pupils (and parents) were reminded they could withdraw at any time. To minimise disruption and safeguard participants, all activities and data collection took place during the schools' normal timetabled classes. Standard school gatekeeping procedures applied for all adults with face-to-face access to pupils (including Art Facilitators and the observing researcher). As Art Facilitators and school teachers led the delivery of the intervention, the researcher was positioned as an researcher in classes, rather than directing participation. Privacy and confidentiality were ensured through anonymised collection; we deliberately chose not to audio or video-record the sessions, and the researcher authored the data in an anonymised manner. The survey was collected anonymously as well. As such, the research team was not privy to any student-identifiable data.

3.3 Participants

Twelve subject-specific teachers participated in the delivery of the project, and a total of 11 Year 7 cohorts participated in the project (7 from school A and 4 from school B, each class comprising 24-30 pupils). In total, approximately 420 pupils completed the curriculum units set in this project. While the 11 participating classes included pupils with a wide range of abilities, an additional mixed-age SEND class (School B) also completed the curriculum unit, allowing us to capture the learning experiences of a wider range of diverse learners.

3.4 Subject Areas, Project Phases, Curriculum Units & Technologies

The study was organised into four phases aligned with the schools' academic calendars. The study took one academic year to complete, from planning to delivery.

Autumn Term: Co-Planning, Curriculum Design & Preparation. In this term, researchers, the Charity Partner, Art Facilitators, School administrators, and school teachers collaboratively set initial meetings to explore the potential of process-oriented approaches using art-based practices through technology and how such approaches could be embedded into their existing curricula. Depending on each school's vision, needs, and existing shortcomings, School A chose to focus on art as a subject, while School B chose to focus on history.

Following initial scoping, the collaborative team shifted to exploratory design sessions to identify curriculum-relevant topics for each subject, consider how technologies might be incorporated, and develop classroom activities and supporting resources. These decisions were shaped by the realities of deployability in everyday school routines—what equipment schools already had, what the Charity Partner could feasibly provide, and what Art Facilitators could reliably deliver within the allotted time. These constraints reflect the limitations mentioned within the body of HCI research, where bespoke educational systems often underestimate logistical and material constraints in practice [92]. Given tight budgets typical of under-resourced, low-socioeconomic settings, we deliberately excluded paid or bespoke software and instead focused on free-to-use, off-the-shelf applications alongside the hardware that can be realistically sourced by the Charity Partner.

Whilst the meetings were carried over a period of 14 weeks, the meetings (introductory and design sessions) varied in frequency depending on the availability of the project partners, the time constraints faced by school administrators and teachers, and the Art Facilitator's schedule. A total of 3 meetings were conducted. Meeting minutes were recorded to capture key discussion points, decisions, and next steps. The notes were 0.5-1 page long on average.

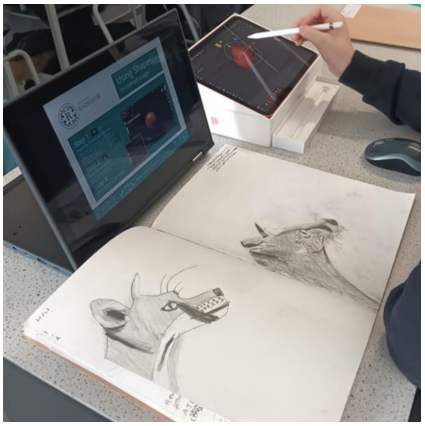
Towards the end of the term, the Art Facilitators and school teachers developed a clear understanding of the units they were to deliver in each school, as well as the frequency and duration of each unit. Ultimately, the curriculum at each school was organised into three units, each comprising three one-hour classes over a two-week period. Therefore, for each school, process-focused art-based activities were delivered over 6 weeks (over 9 one-hour classes).

To ensure the curriculum is manageable to deliver (i.e., with consideration to logistical issues such as Art Facilitator's availability and equipment sharing across two schools), the project partners decided to deliver the curriculum one school per term.

Spring Term: School A Arts Curriculum Delivery. The curriculum was delivered in art lessons at School A throughout the spring term. The frequency of these lessons depended on the school's schedule for Year 7 art lessons. During each one-hour class, pupils were seated in pairs and swapped turns interacting with the technology, with one peer learning by observing or supporting the other. Across the span of 9 classes, the Charity Partner and Art Facilitators designed the units so that pupils engage with different technologies (i.e., VR and tablet), as well as a range of digital art formats (i.e., 3D sculpting, 2D art, and photogrammetry), with the aim of developing their creative, technical, and critical capacities through hands-on digital art making. Specifically:

- **Unit 1: Digital Clay.** Pupils used Nomad Sculpt [3] on tablets to create 3D digital clay models based on their pencil sketches. For example, pupils transformed two-dimensional animal drawings into three-dimensional digital sculptures (see fig. 2).

[3] https://nomadsculpt.com



(a) A pupil translating their traditional sketch to digital sculpting.



(b) A close-up of a student's 3D model version of their sketch.



(c) The classroom ecology during the intervention session.

Figure 2: Snapshots of School A Digital Clay Intervention.

- **Unit 2: Digital Photography and Photogrammetry.** Pupils learned photogrammetry using the Scaniverse [4] app on tablets to create three-dimensional models from photographs. They combined these models with 2D Islamic art elements and used Procreate [5] to colour and collage the images, resulting in digital collages (see fig. 3).
- **Unit 3: VR Painting.** Using VR headsets equipped with OpenBrush[6] and tablets with Procreate, pupils painted in three-dimensional virtual space, drawing on themes from Renaissance art (i.e., forms of arts from the 14th-16th centuries in Europe) as inspiration for their compositions.

Summer Term: School B History Curriculum Delivery. The curriculum was delivered in history lessons at School B throughout the summer term. The frequency of these lessons depended on the school's schedule for Year 7 art lessons. During each one-hour class, pupils worked in small groups, supported by one Art Facilitator and their history teachers. Pupils engaged in digital arts-based practices that were refocused to be history-centred. Similar to School A, the Charity Partner and Art Facilitators utilised tablets and VR headsets across varied contexts in order to introduce students to a range of approaches to digital art-making. Specifically:

- **Unit 1: AR Museum.** Pupils conducted AR photogrammetry on local historical sites. Using the tablet-based app, Scaniverse, they created three-dimensional AR models of locations with local historical significance, with the aim of curating a virtual museum.
- **Unit 2: Transport Memorial.** In collaboration with a local museum, pupils used Nomad Sculpt on tablets to design 3D memorials relating to themes of transport and local history.
- **Unit 3: 'Fair Prisons'.** Pupils were introduced to historical debates about crime and punishment and tasked with designing a 'fair prison'. They first sketched 2D floor plans on paper and then used Arkio[7], an architectural design application, together with tablets and VR headsets to construct and explore their designs in VR (see fig. 1).

3.5 Data Collection

We drew on two sources of data for the study: classroom observational notes *[OBS]* authored by one researcher and a pupil survey *[SUR]* that was administered at the end of the term.

- **Observational Notes.** The sessions were not audio- or video-recorded due to the ethical and practical sensitivities of conducting research with children in school settings. Avoiding recording was intended to minimise intrusion, reduce safeguarding and anonymity risks, and preserve the more natural classroom environment. Instead, the researcher produced detailed observational notes during each session, which were written up and expanded immediately afterwards. Notes recorded what happened during lessons (e.g., task structures, use of technologies, interactions around tools and materials) as well as reflective comments on classroom atmosphere and dynamics. The observations focused in particular on: (i) how teachers, artists and the arts partner worked together to introduce and manage the use of immersive and non-immersive digital technologies; (ii) how pupils related to the technologies in practice, including moments of confidence, difficulty and workaround; and (iii) how classroom dynamics, including collaboration between pupils and the teacher–pupil relationship, shifted as process-based, open-ended tasks unfolded over time. Any pupil speech reported in the notes should therefore be understood as contemporaneously recorded, but is not necessarily a verbatim transcription. As such, quoted extracts represent close approximations based on in-session note-taking and immediate post-session elaboration, and are used to convey the substance and character of pupils' contributions. To enhance the trustworthiness

[4]https://scaniverse.com
[5]https://procreate.com
[6]https://openbrush.app
[7]https://www.arkio.is



(a) One student's digital tile. (b) Another student's digital tile. (c) The classroom ecology.

Figure 3: Snapshots of School A Digital Photography and Photogrammetry.

and accuracy of details captured, the observational notes were shared with teachers and Art Facilitators for corroboration. For each class observation, notes were 1.5-2.5 pages long.

- **Pupil Survey.** At the end of the term, upon completion of the intervention, pupils in School A were invited to complete a short paper-based survey in class about their experiences over the curriculum units. A total of 176 responses were obtained. The survey was constructed in collaboration with the teachers and used simple language to make sure that the pupils understood the questions asked. The survey included a series of open-ended prompts about the activities carried out in the arts curriculum units. The questions asked pupils to describe and reflect on:
  - Whether they enjoyed working with technologies and the apps they used;
  - How they created their digital artworks from their initial form to the final output;
  - What went well, the challenges they encountered, and how they overcame these challenges;
  - In what ways they felt they had developed as artists;
  - What kind of skills and techniques they gained through these classes;
  - The perceived advantages and disadvantages of using technology to create digital art;
  - Whether they preferred digital over traditional art-making techniques and why.

As for School B, it was not possible to collect and administer the pupil survey due to the large class sizes and the prioritisation of class activities over research-related data collection.

3.6 Data Analysis

The observational notes and open-ended survey responses were collated into a single corpus and analysed using Reflexive Thematic Analysis (RTA) [8, 9]. Consistent with RTA, we did not apply a predefined codebook, and instead, we treated themes as analytically generated through researchers' engagement with the data. Three co-authors (researchers in HCI) led the analysis in close collaboration with the wider research team. In line with RTA's emphasis on reflexive interpretation rather than procedural reliability [8], analysis proceeded inductively. The three authors familiarised themselves with the corpus and wrote initial analytic memos, which were discussed across a series of meetings. These discussions also included the community arts researcher who authored the observational notes, thereby supporting a shared understanding of the classroom context and pedagogical intent. Inductive coding was then undertaken across the dataset. The three co-authors led coding, with another two co-authors (a researcher in technology design and a researcher in HCI) contributing through parallel reading, discussion, and cross-checking of interpretations. Following initial coding, the research team (researchers in HCI (n=4), creative practice (n=3), education and social work (n=1)) synthesised the codes with example excerpts of data using a shared Miro board to facilitate collaborative analysis. Codes and associated data extracts were clustered into candidate themes. Candidate themes were iteratively refined through discussion with the research team, with attention to internal coherence, distinctiveness, and alignment with the research questions.

4 Findings

Overall, the findings were organised, presented and discussed to answer the following questions: **RQ1:** How does process-based technology-mediated creative learning shape the development of pupils' HOT skills? **RQ2:** What classroom-ecology changes emerge when immersive and non-immersive digital tools are used in collaborative creative pedagogies? **RQ3:** What breakdowns, constraints, and trade-offs condition the deployability of a bottom-up, off-the-shelf creative technology curriculum in low-socioeconomic secondary schools, and what lessons learned from deployment can help with facilitating resilient implementation?. We therefore report the following cross-cutting themes that foreground process-first learning as it unfolded in the classroom. Specifically, the themes *Creative Exploration Through Digital Possibility Spaces*, *Risk Taking as a Critical Ingredient for Process-Based Pedagogy*, and *Critical*

Thinking speak primarily to RQ1 by showing how iterative making, revision, judgement, and evaluation were enacted in practice, while also revealing the altered participation structures and pedagogical relations associated with RQ2. The theme *Social Learning as a Core Learning Mechanism* is most closely tied to RQ2, while also showing how peer-supported interaction contributed to pupils' reasoning, persistence, and self-regulation in ways relevant to RQ1. Finally, the theme *Breakdowns & Workarounds: A Practical Reflection on Deployment* addresses RQ3 most directly by foregrounding the practical conditions that shaped what could be achieved in situ. As such, these themes respond to the research questions at three interconnected levels: they show how HOT skills were supported through process-based creative practice; how technologies reshaped classroom ecology by redistributing talk, support, authority, and participation; and how implementation was co-produced through the contingencies of real-world deployment. Throughout, we used short extracts from observation notes to capture interactional details (e.g., turn-taking, talk, classroom management, tool breakdowns) and survey excerpts to show how pupils themselves framed affordances, frustrations, and perceived learning.

4.1 Social Learning as a Core Learning Mechanism

Collaborative learning scholarship has long emphasised that progress in open-ended tasks is not produced solely through individual cognition, but through *socially organised regulation* — peers jointly framing problems, distributing attention, and coordinating strategies and affect in situ [32, 41]. Consistent with this view, our data show that process-centred, tool-mediated sessions reconfigured the classroom's coordination infrastructure: pupils' talk became a primary site for instructional work (micro-tutorials, troubleshooting, decision-making). The following subthemes unpack how peer practices functioned as a mechanism of learning.

4.1.1 Partner Talk & Peer Guidance. Where classroom activity is typically organised through tight, teacher-led sequencing, exploratory sessions exhibited a marked shift from this configuration. Pupils advanced tasks through coordinated joint action—talking, trying, and iteratively adjusting—while teachers and Art Facilitators did not feel the need for such directive control and instead positioned themselves as facilitators who moderated progress, supported troubleshooting, and maintained the conditions for productive exploration.

"I noticed 3 pupils talking as a group whilst moving their shapes. They were not really listening to [the Art Facilitator], but they didn't need to; they were actually moving their shapes successfully" [OBS][8].

Across sessions, partner talk functioned as a primary mechanism through which pupils navigated unfamiliar tools and sustained progress. Rather than routing questions through teachers or Art Facilitators, pupils routinely turned to one another for guidance.

> "*Pupils often turned to peers rather than adults for guidance, and some even commented that they see themselves as 'teachers' for their partner [...] evidence of pupils talking through technical issues with each other*" [OBS].

At a surface level, these exchanges were largely concrete and interface-specific—micro-tutorials embedded in the flow of work that helped peers navigate technical breakdowns (e.g., *"How do you go into space?" / "You can just scroll down until you find it"*) [OBS]. Reading more analytically, however, partner talk also signalled an identity shift in how pupils positioned themselves within the learning process: by instructing and supporting others, some began to frame themselves as legitimate sources of knowledge (e.g., *"I've never thought about being a teacher before!"*) [OBS], moving from passive recipients of instruction toward active contributors and peer supporters. This re-positioning was not merely rhetorical; it was enacted through the situated practices of peer guidance that structured pupils' work. Pupils repeatedly enacted the role of a *"teacher"* through micro-exchanges that surfaced discoveries, translated interface features into actionable instructions, and scaffolded one another's progress in real time. For example, many pupils shared affordances as they encountered them (*"You can draw a rainbow with the brushstrokes!"*) [OBS]. They also used talk to appraise options, negotiate difficulty, and steer decisions, effectively co-authoring what counted as a workable plan: *"I'm going to draw this one" / "Try that one, it looks easier!"* [OBS]. Pupils framed communication as integral to making and planning: *"I had to share and offer ideas[...] think about my design and my next move[...] ask questions so I could understand the app better"* [SUR, P84][9]). Pupils also stated how they explicitly positioned peer support as a resource for persistence and troubleshooting: *"it was difficult at first, but I asked my partner for help" [SUR, P63]; "my partner helping me, guiding me"* [SUR, P140].

4.1.2 Emotional Growth Through Social Learning: Learning The Art of Care & Repair. Typically, secondary classrooms can be shaped by competitive dynamics that inhibit help-seeking and, at times, spill into disruption [47]. In contrast, we found that the explorative nature of the activities introduced has cultivated a more team-oriented mode of participation: pupils treated peers as collaborators rather than competitors, and partner work was described as *"quite effective"* relative to more individuated formats that could feel like *"divide and rule"* [OBS]. Within this collaborative configuration, social learning did not only support task completion; it also became a vehicle for collaborative thinking and solution-finding:

> *"After this group have been struggling for some time, one peer screams: we've found a creative solution! We can use these pictures to trace with!"* [OBS]

Furthermore, it was clear that through such a collaborative working mechanism, pupils build an empathetic understanding to one another, leading them to truly listen to one another (e.g., *"I listened to their ideas and actually used them"* [SUR, P45]; *"[...]understanding my partners ideas and taking them into a count"* [SUR, P115]), interpreting humility as a quality for good communication during iterative feedback and refinement loops (e.g., *"I have shown humility by reflecting on previous designs and improving future work"* [SUR, P76]), and finally, offering distress relief at crucial times (e.g., *"my pot got deleted[...] I used my partner's pot to help me continue."* [SUR, P7]. As such, partner support reduced the individual cost of exploration and breakdown, enabling pupils to persist in open-ended activity without collapsing into frustration or disengagement.

[8] [OBS=Observation Notes]

[9] [SUR=Survey, Participant ID]

However, peer interactions were not fault-free; when collaboration fractured, pupils described recognising the harm they had done, showing remorse, and taking action to repair what was broken:

> *"We did have some arguments and I ruined his work once[... I] apologised and tried to make it better and put the work back together."* [SUR, P111]

In addition, there were also times when pupils needed reminders about respecting peer boundaries. For instance, the immersive sessions introduced interpersonal risks that required norm-setting:

> *"During the VR session, [the students] immediately started trying to mess about with the students who have the VR headset on them. The Facilitator immediately stamped down on[...] It is impressive how the group respected each other's boundaries afterwards"* [OBS].

Across these forms of emotional growth, collaboration was not simply a pro-social add-on to creative technology use. Rather, it was part of the pedagogical mechanism by which pupils sustained participation in open-ended work—supporting collective problem-solving, buffering breakdowns, and cultivating repair-oriented relations that made iterative exploration socially viable.

4.2 Creative Exploration Through Digital Possibility Spaces

Across units, the tools created digital possibility spaces where creativity could unfold through doing: trying an idea, undoing it, reshaping it, and following where it led [29]. This process way of working changed the classroom attitude towards achieving the lesson task—from getting it right the first time to learning by testing, adjusting, and discovering. In our data, creative exploration flourished when pupils approached the lesson as an invitation to probe the tool's capabilities and build momentum through iteration. Pupils themselves described this as a kind of "*going further*" with their ideas; one pupil wrote that the iPad "*assisted me to explore my creativity into greater depth*" [SUR, P142].

4.2.1 Releasing Creative Expression. Throughout the sessions, it was clear that pupils' interests in the subject (art or history) varied greatly. Some students even mentioned their lack of interest in the subject, and how using digital tools not only fostered interest in the subject, but also enabled them to produce artwork that confidently made them proud:

> "*During our first lesson, i was too nervous and believed i was not able to create a digital pot. I believed i could not do anything to do with art and that art was just too hard for me. However, after this module i have learnt that as long as you try in what you do, you will succeed in it. I managed to take a risk and try to create a digital pot. I am very happy with the outcome of my pot and i am also proud that i was able to take a risk.*" [SUR, P139]

This change in classroom dynamic was most striking in the VR-OpenBrush sessions, where students repeatedly expressed delight at moving between environments and effects. The researcher noted that "*there was a huge amount of attention given to the different environments*" and that reactions were "*so imaginative*" as students narrated their exploration in real time: "*It's Dr Strange's portal! I'm just stepping through it!*" and "*Hey, it's a chromatic wave!*", "*How can you FEEL it?*", "*It's like your own little world.*" [OBS]. Pupils oscillated between excitement and apprehension "*This is so scary, it's cool, but it's scary!*" [OBS], suggesting that the experience stretched them effectively as well as creatively. This sense of 'art expression' was not only a property of the medium, but also co-produced through facilitation (e.g., how adults framed the activity as exploratory). Importantly, this dynamic was not exclusive to VR. In School B's AR museum-trail activities, pupils also described the scanning experience as simultaneously enjoyable and unsettling ("*It's fun!*"; "*It's scary!*") [OBS], indicating that even less immersive technologies can create an affective stretch that invites creative expression.

Moments of surprise often came from immersion in the interaction itself rather than from an intended final product (e.g., "*Hey, I just touched the colours!*" [OBS]), and how exploration was frequently a way of tuning into the tool's affordances as they emerged in the moment. Although this pattern was most clearly articulated in School A's VR-OpenBrush art sessions, a related sense of playful immersion also appeared in School B's VR Arkio lesson when VR time was used for freer tool exploration. Here, the class teacher allowed pupils to choose their own groups and move around, and the researcher recorded spontaneous, joyful experimentation (e.g., surprise at hand-tracking and playful graffiti-like markings).

We saw the potential for social norms to influence immersion. For instance, the researcher noted at School A, whatever the students made in VR was not easily legible to others, so they felt "*less seen*" and therefore "*less judged*" making playful experimentation feel safer [OBS]. However, this reduction in judgment was contingent rather than automatic. When VR work was made more publicly legible (e.g., by linking a headset view to the whiteboard), moments of performance anxiety surfaced ("*You can all see my art!*"; "*This is actually so embarrassing!*" [OBS]) suggesting that the "*less judged*" dynamic depends on how visibility is configured and managed in the classroom.

4.2.2 Anchoring Exploration to Disciplinary Aims. Across both subjects, the most productive moments of creative exploration were when pupils (and adults) tried to connect what the tool made salient to what the lesson was '*about.*' When that connection held, the possibility space became a resource for subject-specific meaning-making. However, when the pedagogical goals attempted to constrain the possibility space, the tool's most compelling affordances, effects, colours, textures, and shortcuts could pull activity toward aesthetic play or workflow completion, causing the curriculum to fade into the background.

In School A art lessons, this mismatch was most visible in the Procreate/Islamic tiles sequence, where technical steps often dominated attention away from the pedagogical aims of learning about Islamic art. The researcher noted that pupils could describe what they were doing as making "*the background*" but "*couldn't specify what it was for*" [OBS]. For example, with aesthetic decisions, the pupils were prompted to use blues/greens linked to Islamic tile traditions, but many chose reds and pinks because "*I like/prefer using reds/orange/pink*" and continually framed choices through preference rather than the art-historical anchor. Some reworked backgrounds into swirl patterns despite being asked not to, with the researcher suggesting the tactile satisfaction of making swirls as a

compelling "*pull*" of the tool [OBS]. This sense of being pulled into aesthetic flow also appeared in survey reflections, as one student noted:"*The pattern i did was just a freestyle sort of manoeuvre and just decided to go with the flow.*" [SUR, P4]. While P130 described that "*the pattern of my digital print was a neon pink and purple, it was swirled and twiste[d]*" they also noted how they tried to tie it back to the lesson "*we then added a large flowers and vines to give our artwork an islamic effect*" [SUR, P130]. Even the adults struggled to negotiate between encouraging creative flow and achieving lesson objectives. The facilitator, when asked what he would do about colour choices, planned to re-emphasise the Islamic art element but admitted reluctance to override choices that "*popped*" visually [OBS]. In practice, the possibility space was co-managed, sometimes tightened toward the disciplinary story, sometimes allowed to run on its own momentum.

In School B History lessons, the same tools illustrated the enhancement to learning that could come with alignment between the tool's affordances and the lesson objectives. The observation notes suggest that pupils seemed most confident when history meant *"finding answers through researching sources"* were less sure about what it meant to use creativity as part of historical work, with one higher-attaining pupil expressing a gap between intention and form: "*It's not the same as what's in my head*" [OBS]. Against that backdrop, the possibility space sometimes functioned as a bridge between feeling, evidence, and explanation. After being introduced to archival materials about child transportation and punishment, the researcher noted the class was "*completely engaged*" and shocked by the image of a public flogging [OBS]. In Nomad Sculpt, pupils used metaphor and narrative to make sense of that evidence. One group reframed a fantastical "*dragon fly boat*" as a "*prison hulk*" or "*boat wreckage*" where "*they've drowned in the ocean*," prompting peers to ask "*Was it sabotage?*" and "*Did it actually sink?*". Another pupil justified a colour choice by linking it to punishment: asked "*why is it red?*" they replied "*It's the blood from the lashes*," while another described "*prison cells*" along the bottom of the ship [OBS].

4.3 Risk Taking as a Critical Ingredient for Process-Based Pedagogy

Throughout the observation data, it was clear how 'erase' and 'undo' operated as infrastructural features that lowered the penalty of error and thereby made iteration a legitimate, routine mode of working rather than a signal of failure:

> *"The main advantage with digital clay was that it could be erased easily and started again"*
> *"Deleting work on an app is less disturbing than ripping up work"*
> *"A similar dynamic was visible in School B's iPad-based making, where pupils repeatedly moved between trying an idea and revising it in response to prompts and peer feedback, treating the artefact as something to continually rework rather than 'get right' in one pass"* [OBS].

In this sense, what later appeared as 'creativity' in the final artefact was underpinned by a process shift: pupils were more willing to attempt bolder moves because wrong turns were inexpensive and reversible. In fact, pupils frequently framed risk-taking as the mechanism through which learning progressed—trying things that might 'ruin' an artefact, then evaluating and adjusting. One pupil described deliberately taking a risky step and discovering that it improved the outcome: "*I did some things that I knew that could ruin my vase but I still did it anyway and the results came out better"* [SUR, P24]. Others articulated a broader logic of exploratory learning, where varied tools and techniques made discovery continuous (*"There are a lot more options and techniques[...] you can find out new things often, helping you to improve each time"* [SUR, P175]) and where partial failure was reframed as productive information rather than a stopping point (*"took some risk[...] some did not turn out well but most did"* [SUR, P102]). The ability to undo supported this stance by enabling rapid, low-commitment trials: *"you might think, 'What about this colour?' [...] and if you don't like it, you can use the undo button"* [SUR, P14]. Here, risk-taking was not merely permitted; it was incentivised as an epistemic strategy for exploring a design space.

Pupils also linked undo/redo to enjoyment and reduced frustration, particularly because restart and revision were quick and non-destructive. One pupil connected 'restartability' to imagination and visualisation: *"We use more imagination[...] and the easiness to restart your pot if you mess up"* [SUR, P37]. This suggests that ease of revision supported a more playful, less anxiety-laden orientation to making. Another explicitly contrasted the temporal and affective costs of physical rework with digital rollback: *"you can make it super quick[...] and if you make a mistake you can[...] go back[...] while a physical you can not"* [SUR, P111] (something that also potentially helped with social repair, see 4.1.2). As such, reversibility did not simply speed up production; it changed the emotional calculus of experimentation by reducing the friction and perceived labour of 'getting it wrong,' thereby helping pupils stay engaged through repeated cycles of trying and adjusting.

Several pupils described digital sculpting as offering a materially legible space for experimentation—supporting manipulation, playful deformation, and repeated reworking in ways that resembled familiar craft practices. One pupil emphasised tactile metaphors of shaping: "*pinch and drag[...] create random holes like in real life[...] it made me feel as I was playing with real clay"* [SUR, P133]. Others framed the medium as effectively unlimited-"*with virtual art apps you can use it as often as you like*" [SUR, P8]; *there is no limit, the imagination is your only limit"* [SUR, P140] —which positions iteration as both economically and imaginatively sustainable. As such, these findings suggest that 'low-cost experimentation' was not only a property of the interface but a perceived condition of possibility: the tools made repetition, divergence, and reworking feel viable within the constraints of classroom time and material scarcity.

4.4 Critical Thinking

Critical thinking is evidenced by children displaying the following abilities: analysing arguments, claims or evidence; making inferences using inductive or deductive reasoning; and evaluating and making decisions or solving problems [49]. Work has focused on making technology as a means of encouraging children to think critically about technology (e.g. [50]), but our data illustrates that simply embedding technology as a means of making can encourage critical processes. The following subthemes evidence how making

helped students work through lesson topics but also question the value of what they were producing.

4.4.1 When making becomes thinking. Throughout the sessions, there were frequent instances where pupils turned making into a prompt for explanation and critical engagement. Pupils were asked (implicitly and explicitly) to account for what they were doing, whether it was 'working,' and why certain choices felt fair or meaningful. Observation notes captured that this values-work was uneven: when asked to design for rehabilitation, the researcher noted limited "*empathy*" and suggested the year 7 group "*can tend to reflect ideas from older adults and family members*" rather than forming their own opinions [OBS]. Later, when pupils were asked to draw their own prison cells, a teacher interpreted some designs as "*they may have been drawing the sort of cells that they might prefer themselves, perhaps being more empathetic,*" while the researcher remained unsure whether this reflected pupils' reasoning or closer following of a "*modelled design*" [OBS]. Here, making became a way to externalise and argue about historical ideas (fairness, punishment, rehabilitation) rather than only completing a product.

In School A, critical engagement surfaced through pupils' standards for their work. Across photogrammetry and Procreate sessions, the researcher repeatedly captured how pupils monitored quality, questioned competence, and made strategic decisions about what to keep, undo, or delete. For example, pupils became frustrated when Scaniverse/photogrammetry outputs were lower quality than expected, sometimes initially treating this as personal failure until reassured it was a software constraint [OBS]. Similarly, the notes captured patterns of deleting work (or deleting and redoing late into a session) as pupils tried to manage how their competence might be evidenced in a medium where mistakes can be erased without a trace, unlike physical work that leaves a visible residue [OBS]. Nonetheless, not 'all' actions are untraceable, and some can even be used for critical and reflective evaluation on in-progress work. For instance, using Procreate's time-lapse process[10], pupils were able to understand where their work was heading and evaluate their steps as they went [OBS].

4.4.2 Questioning Authenticity & Ownership. The findings show that pupils were not only evaluating the quality of their outputs; they were also evaluating the medium and its implications for what counts as art, authorship, and value. For some, digital making raised questions of authenticity and expressiveness: they framed 'virtual art' as missing qualities they associate with human presence in handmade work. One pupil articulated this as a loss of affective trace and intention:

> "*The disadvantages of using technology to create virtual art are that it lacks the personal touch and emotional depth that comes from a human artist and it may lack the creativity of manual art*" [SUR, P142].

In this register, the issue was not whether the artefact looked 'good,' but whether the process and result could carry the kinds of meaning pupils associate with embodied, human craft. Another recurring question of the students was with the idea of software-mediated 'perfection' and perceived sameness. While many pupils experienced the tools as freeing—less worry about ruining materials, easier iteration—others experienced the same properties as restrictive because they seemed to impose a uniform aesthetic. One pupil contrasted the independence of physical making with the standardising effects they attributed to Nomad:

> "*By using physical art you are able to be more independent and your able to do exac[t]ly what you want. By using NOMAD the lines are perfect and everything is the same, meaning its just to[o] perfect*" [SUR, P130].

This suggests that the very affordances that made experimentation exciting (e.g., smoothing, undo, automatic correction) also risked being read as diminishing individuality—especially when pupils valued imperfections as evidence of personhood and process.

Relatedly, pupils invoked material trace and tactility as important criteria for 'realness.' Several accounts positioned traditional making as more meaningful because it preserves marks of the hand that can be both seen and felt.

> "*I definitely prefer the traditional way of doing it because I like to be able to make all of the markings by hand. When they are done I like to be able to feel over the markings by hand and see all of the detail added*" [SUR, P124]

Here, 'real' art was not defined by representational accuracy, but by contact: the artefact carried evidence of the maker through texture, friction, and durable marks—qualities that pupils felt were attenuated or absent in screen-based production.

Pupils also used the activities to reason about ownership and authorship in digital contexts. Some expressed anxiety that digital artefacts are easier to appropriate, which shaped their sense of control over their work: *"someone could download it and claim it as their own"* [SUR, P171]. Others raised a different authorship concern: when the interface strongly shapes the output, pupils can become uncertain about what portion of the artefact is *"theirs."*

> "*It was too perfect and I got confused because the tools made it look good and I did not know if it was me or the iPad*" [SUR, P128].

Importantly, pupils did not uniformly reject this redistribution of agency. For some, tool assistance was valued precisely because it reduced barriers to participation in practices they otherwise perceived as requiring *"talent"*(e.g., *"[Digital art is] good as you dont need much talent or 'skill' where as 'normal' art you have to paint it and you need to be able to do pottery"* [SUR, P57]. These statements complicate any simple reading of 'authenticity': the same features that some pupils interpret as undermining artistic agency are, for others, what make artistic participation possible.

5 Breakdowns & Workarounds: A Practical Reflection on Deployment

In under-resourced schools, the success of exploratory digital making was not a property of the tools alone but an accomplishment produced under, and continually negotiated within, real classroom constraints. Across both sites, the 'possibility' of process-based learning depended on boundary conditions such as technical reliability, device access, short lesson windows, and available support

[10]Procreate *"records every step of the creation of your image. This then compiles it into a high-speed video replay you can export and share."* [80]

for teachers to facilitate sessions in ways they were not accustomed to. In School A, network and file constraints repeatedly shaped what counted as feasible work: when connectivity or scan quality failed (e.g., distorted images), pupils could not always use their own materials and the lesson shifted toward preloaded assets prepared by the charity [OBS]. When apps crashed or work was lost, exploration collapsed into recovery, and the activity advanced through ad hoc workarounds rather than planned extension—often with adults effectively acting as the infrastructure that kept participation moving.

The deployment breakdowns and limitations were shaped in part by the specific technologies used in this study. These devices were not selected solely according to the needs of the project, but were constrained by what the Charity Partner could source and what the Art Facilitators could realistically deliver in situ. Consequently, the challenges observed were inseparable from the material and logistical characteristics of the devices themselves, which influenced participation, pacing, and classroom management across sessions. For instance, for some technologies, access constraints redistributed who could explore, for how long, and with what continuity. In AR sessions across both schools, device-sharing and short turns compressed exploration into hurried cycles, limited opportunities for extensive modelling and reflection, and generated waiting time that raised the noise level and made off-task drift more likely [OBS]. In School B, these dynamics were intensified by routine pressures (i.e., late arrivals, sanctions, uniform enforcement) and environmental factors (i.e., hot weather), which reduced time-on-task and made sustained making harder to maintain [OBS]. In early Arkio sessions, headset setup and changeovers absorbed facilitator attention, leaving some pupils waiting with little to do; time limits meant not all pupils got to use the VR headset, and *"the room became noisier and more distractible because access to the immersive space was unevenly distributed"* [OBS]. However, lesson management proved to be more robust when pupils first built confidence with the iPad interface and VR was framed as *"just another interface,"* enabling smoother turn-taking and freer exploration [OBS]. In addition, the lessons' fragility was heightened when recognised authority was absent: when substitute teachers appeared disengaged, pupils mirrored that stance and tasks drifted toward peer performance, raising uncertainty around discipline and safeguarding [OBS].

These deployment conditions interacted with pupils' uneven familiarity with digital tools and with the stability of classroom authority. For some pupils, unfamiliarity demanded persistence and produced identifiable confidence gains ("*In the start I could not use the tools efficiently[...] but then I kept going and I made a good pot*" [SUR, P40]; "*I had persevered and have learnt how to use the gizmo tool*" [SUR, P22]). Others described the tools as opening participation into art (e.g., "*Before I did not like art but now I have started to like it*" [SUR, P45]) and as supporting strategic planning tools (e.g., "*first I will do it digitally[...] avoid disasters so I can then do it physically*" [SUR, P4]). And some pupils saw the exposure to technologies was of value in its own right (e.g., wanting to "*learn more about NOMAD sculpt[... because they] want to be a game developer*" [OBS]).

6 Discussion

This study contributes an in situ account of how process-first learning can become workable at scale in everyday secondary classrooms. Across a charity-led digital arts programme in two low-socioeconomic schools (400+ Year 7 pupils), we saw pupils shift from cautious, task-compliant participation toward exploratory agency when adults created *structured permission to experiment*. Integrating technology into lesson curriculum, something that is relatively rare in HCI [90], encouraged students to focus on the creative process instead of the outcomes, allowing them to illustrate critical HOT skills in action such as problem-solving (trial-by-error exploration of the tool), creativity (no longer feeling limited by resources), and self-regulation (learning and repairing social boundaries). By focusing on making, pupils were also given a chance to develop their critical thinking skills by mimicking empathetic design, reviewing their work through time-lapse features, and questioning the value of virtual art. Despite these positives, we also found that persistent limitations due to resources (i.e., time, infrastructure, classroom management, tool familiarity/availability) still hindered the success of the intervention at times, even with attempts at mitigation. In this section, we discuss how process-learning through technology supports children's agency and considerations for the deployment of technology in under-resourced classrooms.

6.1 Process-First Learning as a Pathway to Pupils' Agency

Agency and autonomy have many facets [7], we treat agency here as contextual and interactive: something pupils *do* in relation to classroom norms, materials, and others, rather than an individual trait that some pupils simply possess [55]. In this sense, creative exploration emerged as a *classroom achievement*, sustained by shared routines that made trying, revising, and discussing work socially legitimate. In this way, the interdependent collaborative learning environment [44] that helped develop creative artefacts that aligned with the lesson aims created a collective view of agency. We note that we do not see this interdependent expression of agency as overshadowing or working against any child's independent expression of agency but as another means of supporting independent agency. As noted by Waters et al. [94], peer support is critical in Year 7 for making the transition to secondary school positive. For instance, we saw how through collaboration, individual children could *"understand"* and *"tak[e]"* their partner's ideas into consideration as a means of making their own outputs. Technology as the object through which learning is expressed served as a conduit for sharing and reflection, which Resnick [76] noted are fundamental building blocks for helping learners develop creative-thinking skills and agency.

Because we recognise a pupil's independent agency as contextual, it is important to acknowledge that permission to express agency was made concrete by the adults in the classroom. Adults, such as teachers and the Art Facilitator legitimised partial progress and unfinished work, framed mistakes as expected, protected time for second attempts, and used talk that positioned pupils as decision-makers (e.g., asking what they tried and why, rather than only checking whether they followed instructions). Potentially, we have to acknowledge that some of this reflection may not have happened

if the observer was also not present. This resonates with recent work on classroom error climate, which shows that how errors are treated (by teachers and peers) shapes whether students experience mistakes as threatening or as usable learning opportunities [23, 64, 85]. Pupils' own questions (e.g., *"How do I erase it? Am I allowed to erase it?"*) make visible that experimentation often depends on explicit signals that revision is acceptable behaviour, especially under outcome-driven schooling conditions. Other researchers have noted that teachers' attitudes towards a subject will influence their students' feelings towards and academic performance in that subject [56, 89]. For instance, the Art Facilitator modelling empathetic designs of prisons using the tool set the trajectory for the children to engage with the lesson material differently from their initial apathetic reactions.

While constructionism focuses on being contextual ("*less us, more them*" [86]), the collective agency of the classroom depends on the teachers also being able to express their own agency. As Ibrahim et al. [36] noted, having a 'technology' lead within a school can be useful; however, collaboration between teachers is often not supported. Supporting collaboration between teachers or with third-party technologists could help to ensure disciplinary aims do not fade into the background. While the hope was to achieve something akin to the Technological Pedagogical Content Knowledge (TPACK) model [14], in which content, technological, and pedagogical knowledge interact and connect, this was not wholly successful. Particularly with under-resourced schools, taking into account that technology may need to be taught from zero is necessary for planning lesson objectives. Instead of immediately combining the technology with content knowledge, content should be separated a bit more at first from technology and then combined in a way that allows it to reinforce learning.

6.2 Deployment Barriers, Opportunities & Trade-Offs in Under-Resourced Schools

Scheepmaker et al. [82] acknowledge that integration of technologies is highly dependent on contextual restraints that can vary beyond those challenges linked to teacher requirements (i.e., a school's IT budget, confidence of teachers [19]). As our research points out, a lack of resources can be complex, particularly when we are looking at low-resourced schools within high-resourced countries. As Michaelis and Weintrop [59] noted, the existing structures and institutions can bias how resources are distributed, making assumptions that certain pupils would not be able to or would not gain as much knowledge as others in certain disciplines. Schools may have partial access or no access to various resources, which can add to uncertainty with lesson planning and hinder constructionist learning. For instance, the poor IT infrastructure at School A meant that the internet connection hindered the students' ability to scan their own photographs. During initial meetings, the charity realised this may be an issue and mitigated for this by preloading the devices with images. However, using preloaded scans meant that the students were unable to engage in active learning necessary for reinforcing skills [2]. Potentially, as Scheepmaker et al. [82] called for, for pupils to gain the most from technology in the classroom, it is important to reach policymakers to create policies like the UK's 2030 goal to have 5G coverage nationwide [16].

However, as Scheepmaker et al. [82] had suggested, outsourcing technology teaching proved to be an excellent way for under-resourced schools to increase student exposure to a wider variety of digital tools while not increasing teacher workloads by requiring them to keep up with technological advancements beyond what is necessary for their jobs [43]. 'Outsourcing' technology education was seen as beneficial to staff who lacked technology knowledge. However, the teachers' lack of understanding of the digital tools made it difficult to ensure that there was alignment between the lesson aims and the affordances of the devices. Conversely, the charity's lack of time to spend on content and academic objectives prevented them from creating a perfect fit. As a result, the students sometimes struggled with having to retain both lesson aims in addition to learning how to use a new technology. As Lyu et al.'s [54] systematic review points out, potentially the mitigation strategies of Ibrahim et al. may only be feasible for technology teachers who are already integrated into a school (as they can more readily discuss plans or issues in the corridors or staffroom). Specifically, our work highlighted how bringing in a third party to facilitate technology education can further confuse classroom roles, which can hinder the facilitator's ability to teach. For example, when the substitute teacher disengaged from the lesson, their lack of interest in technology encouraged the children to also devalue the ability of technology to keep the subject matter interesting. Therefore, if aiming to rely on networks of people with technical resources as proposed by Scheepmaker et al. [82], consideration that help the school infrastructure to expand its ability to outsource some technology teaching through opening up communication pathways (i.e., having more administrative staff involvement or even student/parent liaisons) could strengthen collaborative effort to rapidly build up new rules and norms.

7 Conclusion

This paper examined, *in situ* and under real-world constraints, what unfolded when creative-subject teaching shifted from outcome-oriented instruction to process-centred learning supported by off-the-shelf immersive and non-immersive digital arts practices in two low-socioeconomic secondary schools. We found that embedding exploratory digital making into everyday lessons encouraged exploration and shifted classroom dynamics: pupils learned through partner talk and peer guidance; negotiated ideas collaboratively; practised care and repair; and treated tools as possibility spaces for iteration, risk-taking, and reflective and mean-making—while also exposing tensions around ephemerality, ownership, and the perceived "realness" of digital outputs. Limitations include the naturalistic, context-bound design, reliance on observational notes as the main source of data, and pupil survey data from School A only. Nonetheless, this paper lays the foundations for a deployable, process-centred approach in under-resourced schools by articulating the interactional mechanisms and practical dependencies that sustained exploration in everyday lessons. Future work could explore the generalisability of our results across subjects and sites, examine credible approaches to assessing and evaluating process-focused curricula, and design scaffolds that reduce the inertia and friction of integrating technology-mediated activities into everyday classrooms.

8 Selection and Participation of Pupils

The work presented in this paper was conducted in partnership with an arts charity organisation and situated in two secondary schools in coastal England (UK) serving low-socioeconomic communities, with high proportions of pupils with SEND and below-average reading ages. As an in situ study, we aimed to explore how digital and immersive technologies shaped learning within routine classroom practice. The Charity Partner—working with volunteer professional digital artists and subject teachers—delivered sustained, curriculum-aligned opportunities for pupils to engage in collaborative, process-based creative work using digital tools. In these under-resourced settings, the programme provided access to pupils to such experiences that would be otherwise inaccessible, unfeasible, while also mobilising local creative expertise and strengthening school–community links.

The study received approval from the Central Research Ethics Advisory Group (CREAG) at the University of Kent (Ref. CREAG059-04-25). The Charity Partner and schools identified appropriate year groups and curriculum subjects. As such, Year 7 (11–12 years) cohorts undertaking the arts subject in School A, history in School B, and one mixed-age SEND class in School B were identified as suitable for participation. All students were considered to participate in this intervention regardless of their abilities and skills. This is to ensure that the intervention was inclusive for all and all Year 7 students undertaking these subjects had an equal opportunity to experiment with technologies. The schools' administrative teams, supported by the Charity Partner, briefed parents on study aims, methods, data collection, and duration; parental consent and pupil assent were collected by the Charity Partner, and pupils/parents were reminded of their right to withdraw at any time. To minimise disruption and safeguard participants, all activities and data collection took place during the schools' normal timetabled classes. Standard school gatekeeping procedures applied for all adults with face-to-face access to pupils (including Art Facilitators and the observing researcher). As Art Facilitators and school teachers led the delivery of the intervention, the researcher was positioned as a researcher in classes, rather than directing participation.

We collected classroom observational notes authored during and immediately after sessions in both schools (later expanded into fuller narratives) and an end-of-term pupil survey in School A with open-ended responses (N=176); no survey was administered in School B due to classroom constraints and prioritisation of teaching time. Privacy and confidentiality were ensured through anonymised collection; we deliberately chose not to audio or video-record the sessions, and the researcher authored the data in an anonymised manner. The survey was collected anonymously as well. As such, the research team was not privy to any student-identifiable data. For analysis, survey responses were analysed to explore pupils' accounts of tool use and creative processes, affective responses (e.g., enjoyment/frustration), perceived affordances and limitations of virtual versus traditional making, and reflections on developing artistic identities. Observational notes were analysed to identify recurring interactional patterns, including how teachers, Art Facilitators, and the arts partner introduced and managed technologies; how pupils appropriated and negotiated tools in practice; and how collaboration and teacher–pupil relationships evolved within open-ended, process-based activities.

Acknowledgments

Elaine Czech and Chee Siang Ang are researchers on the ARISE Initiative, which is funded by UK Research and Innovation and the Department for Environment, Food and Rural Affairs (ES/Y008901/1). We gratefully acknowledge Electric Medway for their valuable community work and their contribution to the success of this project. We also thank the volunteer Art Facilitators, school leadership teams, and teachers at both schools, whose support was essential to the delivery of the project. Finally, we extend our sincere thanks to the parents and pupils who participated in the study. We hope the project has contributed to a positive and lasting memory for those involved.

References

[1] Edith Ackermann. 2001. Piaget's constructivism, Papert's constructionism: What's the difference. *Future of learning group publication* 5, 3 (2001), 438.

[2] Richard Anderson, Ruth Anderson, K. M. Davis, Natalie Linnell, Craig Prince, and Valentin Razmov. 2007. Supporting active learning and example based instruction with classroom technology. In *Proceedings of the 38th SIGCSE Technical Symposium on Computer Science Education* (Covington, Kentucky, USA) *(SIGCSE '07)*. Association for Computing Machinery, New York, NY, USA, 69–73. doi:10.1145/1227310.1227338

[3] Muhammad Shahid Anwar, Jie Yang, Jaroslav Frnda, Ahyoung Choi, Nilufar Baghaei, and Miram Ali. 2025. Metaverse and XR for cultural heritage education: applications, standards, architecture, and technological insights for enhanced immersive experience. *Virtual Reality* 29, 2 (2025), 51. doi:10.1007/s10055-025-01126-z

[4] Samuel Asare, Priscilla Walden, E Aniagyei, and M Emmanuel. 2023. A comparative study of traditional art techniques versus digital art techniques in the context of college visual art education. *American Journal of Arts, Social and Humanity Studies* 3, 1 (2023), 21–34.

[5] A. Bacon. 2023. *The Arts in Schools: Foundations for the Future.* Gulbenkian Foundation.

[6] Predrag Bejaković and Željko Mrnjavac. 2020. The importance of digital literacy on the labour market. *Employee Relations: The International Journal* 42, 4 (2020), 921–932.

[7] Dan Bennett, Oussama Metatla, Anne Roudaut, and Elisa D. Mekler. 2023. How does HCI Understand Human Agency and Autonomy?. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 375, 18 pages. doi:10.1145/3544548.3580651

[8] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 4 (2019), 589–597. arXiv:https://doi.org/10.1080/2159676X.2019.1628806 doi:10.1080/2159676X.2019.1628806

[9] Victoria Braun and Virginia Clarke. 2021. One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology* 18, 3 (2021), 328–352. arXiv:https://doi.org/10.1080/14780887.2020.1769238 doi:10.1080/14780887.2020.1769238

[10] Martin Brynskov, Bent G Christensen, Martin Ludvigsen, Ann-Marie Collins, and Kaj Grønbæk. 2005. Designing for Nomadic Play: A case study of participatory design with children. *Proc. IDC 2005* (2005).

[11] Alyshia Bustos, Nanibah Chacon, Mia Shaw, Fiona Bell, and Leah Buechley. 2024. Interactive Murals: New Opportunities for Collaborative STEAM Learning. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 655, 19 pages. doi:10.1145/3613904.3641987

[12] Campaign For The Arts. 2025. *Arts in the Curriculum: Trends and Impacts.* Technical Report. Campaign For The Arts.

[13] David Carless and David Boud. 2018. The development of student feedback literacy: enabling uptake of feedback. *Assessment & Evaluation in Higher Education* 43, 8 (2018), 1315–1325.

[14] Ching Sing Chai, Joyce Hwee Ling Koh, Chin-Chung Tsai, and Lynde Lee Wee Tan. 2011. Modeling primary school pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) for meaningful learning with information and communication technology (ICT). *Computers & Education* 57, 1 (2011), 1184–1193. doi:10.1016/j.compedu.2011.01.007

[15] Alan Chamberlain, Andy Crabtree, Tom Rodden, Matt Jones, and Yvonne Rogers. 2012. Research in the wild: understanding'in the wild'approaches to design and development. In *Proceedings of the designing interactive systems conference*. 795–796.

[16] Adam Clark and Carl Baker. 2024. *5G in the UK*. Research Briefing CBP-7883. House of Commons Library. https://commonslibrary.parliament.uk/research-briefings/cbp-7883/

[17] Andrew Clayphan, Anthony Collins, Judy Kay, Nathan Slawitschka, and Jenny Horder. 2018. Comparing a Single-Touch Whiteboard and a Multi-Touch Tabletop for Collaboration in School Museum Visits. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 1, Article 6 (March 2018), 23 pages. doi:10.1145/3191738

[18] Construction Industry Training Board (CITB). 2024. *Digital Competence Framework for Construction: Framework Document*. Technical Report. Construction Industry Training Board (CITB). https://www.citb.co.uk/media/fa3lpljn/digital-competence-framework-for-construction-eng-final.pdf

[19] Lyn Dawes. 2012. What stops teachers using new technology? In *Issues in teaching using ICT*. Routledge, 61–79.

[20] Department for Education. 2025. Key stage 2 attainment, Academic year 2024/25. https://explore-education-statistics.service.gov.uk/find-statistics/key-stage-2-attainment/2024-25 Explore education statistics (GOV.UK). Published 11 September 2025; last updated 16 September 2025. Release type: Accredited official statistics..

[21] Department for Education. 2025. *Special educational needs in England: Academic year 2024/25*. Official Statistics. HM Government. https://explore-education-statistics.service.gov.uk/find-statistics/special-educational-needs-in-england/2024-25 Published via Explore Education Statistics.

[22] Griffin Dietz, Jimmy K Le, Nadin Tamer, Jenny Han, Hyowon Gweon, Elizabeth L Murnane, and James A Landay. 2021. Storycoder: Teaching computational thinking concepts through storytelling in a voice-guided app for children. In *Proceedings of the 2021 CHI conference on human factors in computing systems*. 1–15.

[23] Markus Dresel, Martin Daumiller, Jana Spear, Stefan Janke, Oliver Dickhäuser, and Gabriele Steuer. 2025. Learning from errors in mathematics classrooms: Development over 2 years in dependence of perceived error climate. *British Journal of Educational Psychology* 95, 1 (2025), 180–196.

[24] Education Endowment Foundation. 2025. *Metacognition and Self-Regulated Learning: Guidance Report*. Technical Report v2.4.0. Education Endowment Foundation. https://d2tic4wvo1iusb.cloudfront.net/production/eef-guidance-reports/metacognition/metacognition-and-self-regulated-learning_guidance-report.v.2.4.0.pdf Updated guidance report (Version 2.4.0)..

[25] Barry Fishman, William R Penuel, Stephen Hegedus, and Jeremy Roschelle. 2011. What happens when the research ends? Factors related to the sustainability of a technology-infused mathematics curriculum. *Journal of computers in mathematics and science teaching* 30, 4 (2011), 329–353.

[26] Petra Fisser and Annette Thijs. 2015. Integration of 21st century skills into the curriculum of primary and secondary education. In *Society for Information Technology & Teacher Education International Conference*.

[27] Sarah French, Ashton Dickerson, and Raoul A Mulder. 2024. A review of the benefits and drawbacks of high-stakes final examinations in higher education. *Higher Education* 88, 3 (2024), 893–918.

[28] LUDMILLA FO Galvão, LAURA S García, and TANYA A Felipe. 2021. Distributed participatory design platform for game design with deaf children. In *IDC'21: ACM Interaction Design and Children (IDC) Conference*. 2.

[29] William Gaver. 2011. Making spaces: how design workbooks work. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 1551–1560.

[30] Carina Girvan and Timothy Savage. 2019. Virtual worlds: A new environment for constructionist learning. *Computers in Human Behavior* 99 (2019), 396–414. doi:10.1016/j.chb.2019.03.017

[31] Jue-Qi Guan, Liang-Hui Wang, Qu Chen, Kai Jin, and Gwo-Jen Hwang. 2023. Effects of a virtual reality-based pottery making approach on junior high school students' creativity and learning engagement. *Interactive Learning Environments* 31, 4 (2023), 2016–2032.

[32] Allyson Hadwin, Sanna Järvelä, and Mariel Miller. 2017. Self-regulation, co-regulation, and shared regulation in collaborative learning environments. In *Handbook of self-regulation of learning and performance*. Routledge, 83–106.

[33] Ariel Han, Xiaofei Zhou, Zhenyao Cai, Shenshen Han, Richard Ko, Seth Corrigan, and Kylie A Peppler. 2024. Teachers, Parents, and Students' perspectives on Integrating Generative AI into Elementary Literacy Education. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 678, 17 pages. doi:10.1145/3613904.3642438

[34] Björn Högberg and Daniel Horn. 2022. National high-stakes testing, gender, and school stress in Europe: A difference-in-differences analysis. *European Sociological Review* 38, 6 (2022), 975–987.

[35] House of Lords. 2023. *Requires improvement: urgent change for 11–16 education*. Technical Report. Education for 11–16 Committee.

[36] Seray Ibrahim, Asimina Vasalou, and Laura Benton. 2022. Understanding the Situated Practices of School Technology Leaders in the Early Stages of Educational Technology Adoption. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 312, 14 pages. doi:10.1145/3491102.3502120

[37] Munevver Ilgun Dibek, Merve Sahin Kursad, and Tolga Erdogan. 2025. Influence of artificial intelligence tools on higher order thinking skills: a meta-analysis. *Interactive Learning Environments* 33, 3 (2025), 2216–2238.

[38] Andri Ioannou, Ourania Miliou, Maria Adamou, Andreas Kitsis, Stella Timotheou, and Aekaterini Mavri. 2024. Understanding practicing and assessment of 21st-century skills for learners in makerspaces and FabLabs. *Education and Information Technologies* 30, 7 (Nov. 2024), 8829–8846. doi:10.1007/s10639-024-13178-w

[39] Simon J. James, Alan Houston, Lynn Newton, Sophie Daniels, Nicky Morgan, Will Cohu, Anthony Ruck, and Bill Lucas. 2019. *Durham Commission on Creativity and Education*. Technical Report. Arts Council England and Durham University. https://durham-repository.worktribe.com/OutputFile/1634984 Report of a joint commission convened by Arts Council England and Durham University..

[40] Thorben Jansen and Jens Möller. 2022. Teacher judgments in school exams: Influences of students' lower-order-thinking skills on the assessment of students' higher-order-thinking skills. *Teaching and teacher education* 111 (2022), 103616.

[41] Hanna Järvenoja, Jonna Malmberg, Tiina Törmänen, Kristiina Mänty, Eetu Haataja, Sara Ahola, and Sanna Järvelä. 2020. A collaborative learning design for promoting and analyzing adaptive motivation and emotion regulation in the science classroom. In *Frontiers in Education*, Vol. 5. Frontiers Media SA, 111.

[42] Haozhe Jiang, Deqi Zhu, Ritesh Chugh, Darren Turnbull, and Wu Jin. 2025. Virtual reality and augmented reality-supported K-12 STEM learning: trends, advantages and challenges. *Education and Information Technologies* (2025), 1–37.

[43] Amy M Johnson, Matthew E Jacovina, Devin G Russell, and Christian M Soto. 2016. Challenges and solutions when using technologies in the classroom. In *Adaptive educational technologies for literacy instruction*. Routledge, 13–30.

[44] David W Johnson and Roger T Johnson. 2005. New developments in social interdependence theory. *Genetic, social, and general psychology monographs* 131, 4 (2005), 285–358.

[45] Seokbin Kang, Ekta Shokeen, Virginia L Byrne, Leyla Norooz, Elizabeth Bonsignore, Caro Williams-Pierce, and Jon E Froehlich. 2020. ARMath: augmenting everyday life with math learning. In *Proceedings of the 2020 CHI conference on human factors in computing systems*. 1–15.

[46] Sohail Imran Khan, Chamandeep Kaur, Mohammed Saleh Al Ansari, Iskandar Muda, Ricardo Fernando Cosio Borda, and B Kiran Bala. 2025. Implementation of cloud based IoT technology in manufacturing industry for smart control of manufacturing process. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 19, 2 (2025), 773–785.

[47] Lenka Kollerová, Petr Květon, Kateřina Zábrodská, and Pavlína Janošová. 2023. Teacher exhaustion: The effects of disruptive student behaviors, victimization by workplace bullying, and social support from colleagues. *Social Psychology of Education* 26, 4 (2023), 885–902.

[48] Daniel Koretz. 2022. *The testing charade: Pretending to make schools better*. University of Chicago Press.

[49] Emily R. Lai. 2011. *Critical thinking: A literature review*. Technical Report. Pearson's Research Reports. https://images.pearsonassessments.com/images/tmrs/CriticalThinkingReviewFINAL.pdf

[50] Susan Lechelt, Yvonne Rogers, and Nicolai Marquardt. 2020. Coming to your senses: promoting critical thinking about sensors through playful interaction in classrooms. In *Proceedings of the Interaction Design and Children Conference* (London, United Kingdom) *(IDC '20)*. Association for Computing Machinery, New York, NY, USA, 11–22. doi:10.1145/3392063.3394401

[51] Xiao Ping Lin, Bin Bin Li, Zhen Ning Yao, Zhi Yang, and Mingshu Zhang. 2024. The impact of virtual reality on student engagement in the classroom–a critical review of the literature. *Frontiers in Psychology* 15 (2024), 1360574.

[52] Jun Liu, Zile Liu, Cong Wang, Yanhua Xu, Jiayu Chen, and Yichun Cheng. 2024. K-12 students' higher-order thinking skills: Conceptualization, components, and evaluation indicators. *Thinking Skills and Creativity* 52 (2024), 101551.

[53] Arnold Lohaus*, CorneliaEv Elben, Juliane Ball, and Johannes Klein-Hessling. 2004. School transition from elementary to secondary school: Changes in psychological adjustment. *Educational Psychology* 24, 2 (2004), 161–173.

[54] Yao Lyu, Jie Cai, and John M. Carroll. 2025. A Systematic Literature Review of Infrastructure Studies in SIGCHI. *Proc. ACM Hum.-Comput. Interact.* 9, 7, Article CSCW364 (Oct. 2025), 41 pages. doi:10.1145/3757545

[55] Consuelo Mameli, Valentina Grazia, and Luisa Molinari. 2023. Student agency: Theoretical elaborations and implications for research and practice. *International Journal of Educational Research* 122 (2023), 102258.

[56] Iuliana Marchis. 2011. Factors that influence secondary school students' attitude to mathematics. *Procedia-Social and Behavioral Sciences* 29 (2011), 786–793.

[57] Jason K McDonald and Esther Michela. 2019. The design critique and the moral goods of studio pedagogy. *Design Studies* 62 (2019), 1–35.

[58] Andrew M Mcnutt, Anton Outkine, and Ravi Chugh. 2023. A Study of Editor Features in a Creative Coding Classroom. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 121, 15 pages. doi:10.1145/3544548.3580683

[59] Joseph E. Michaelis and David Weintrop. 2022. Interest Development Theory in Computing Education: A Framework and Toolkit for Researchers and Designers. *ACM Trans. Comput. Educ.* 22, 4, Article 43 (Dec. 2022), 27 pages. doi:10.1145/3487054

[60] Michael E Milakovich. 2012. *Digital governance: New technologies for improving public service and participation.* Routledge.

[61] Ministry of Housing, Communities and Local Government. 2025. English Indices of Deprivation 2025: Statistical Release. GOV.UK. https://www.gov.uk/government/statistics/english-indices-of-deprivation-2025/english-indices-of-deprivation-2025-statistical-release Accredited official statistics. Accessed: 2026-01-18.

[62] Jewoong Moon, Yong Ju Jung, Soo Hyeon Kim, Younggon Bae, and Bertrand Schneider. 2025. Fostering innovation at the intersection of maker education and extended reality (XR). *Computers & Education: X Reality* (2025).

[63] Maria Murray, Geertje Slingerland, Nadia Pantidi, and John McCarthy. 2024. Socially Engaged Art Approaches to CSCW with Young People in Rurban Communities. *Computer Supported Cooperative Work (CSCW)* 33, 4 (2024), 645–684.

[64] Susanne Narciss and Ecenaz Alemdag. 2025. Learning from errors and failure in educational contexts: New insights and future directions for research and practice. *British Journal of Educational Psychology* 95, 1 (2025), 197–218.

[65] National Education Union. 2025. *The State of the Curriculum and Assessment in England.* Technical Report. NEU.

[66] NatWest Group. 2022. Social mobility and gender parity in tech. NatWest Group News and Insights. https://www.natwestgroup.com/news-and-insights/latest-stories/diversity-equity-and-inclusion/2022/oct/social-mobility-and-gender-parity-in-tech.html In partnership with Code First Girls..

[67] Eszter Neumann, Emma Towers, Sharon Gewirtz, and Meg Maguire. 2016. *A Curriculum for All? The Effects of Recent Key Stage 4 Curriculum, Assessment and Accountability Reforms on English Secondary Education.* Technical Report. King's College London. https://www.kcl.ac.uk/archive/news/education/news/curriculum-for-all-final.pdf Report commissioned by the National Union of Teachers (NUT). Accessed: 2026-01-18.

[68] Nancy Franziska Nichols. 2023. *A qualitative case study of high school art students' transfer of learning experiences between physical and digital tools.* Northcentral University.

[69] Rebecca Nicholson, Tom Bartindale, Ahmed Kharrufa, David Kirk, and Caroline Walker-Gleaves. 2022. Participatory Design Goes to School: Co-Teaching as a Form of Co-Design for Educational Technology. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 150, 17 pages. doi:10.1145/3491102.3517667

[70] OECD. 2019. *Skills for 2030: OECD Future of Education and Skills 2030 Concept Note.* Technical Report. Organisation for Economic Co-operation and Development (OECD). https://www.oecd.org/content/dam/oecd/en/about/projects/edu/education-2040/concept-notes/Skills_for_2030_concept_note.pdf

[71] Ofcom. 2021. Digital divide narrowed, but around 1.5m homes offline. Ofcom Media Release. https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2021/digital-divide-narrowed-but-around-1.5m-homes-offline

[72] Office for National Statistics. 2020. Coastal towns in England and Wales: October 2020. Office for National Statistics (ONS). https://www.ons.gov.uk/businessindustryandtrade/tourismindustry/articles/coastaltownsinenglandandwales/2020-10-06 Accessed: 2026-01-18.

[73] Seymour Papert and Idit Harel. 1991. Situating constructionism. *constructionism* 36, 2 (1991), 1–11.

[74] Mike Petrich, Karen Wilkinson, and Bronwyn Bevan. 2013. It looks like fun, but are they learning? In *Design, make, play.* Routledge, 50–70.

[75] Xiang Qi and Junnan Yu. 2025. Participatory design in human-computer interaction: Cases, characteristics, and lessons. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems.* 1–26.

[76] Mitchel Resnick. 2007. All I really need to know (about creative thinking) I learned (by studying how children learn) in kindergarten. In *Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition* (Washington, DC, USA) *(C&C '07)*. Association for Computing Machinery, New York, NY, USA, 1–6. doi:10.1145/1254960.1254961

[77] Mitchel Resnick. 2014. Give P'sa chance: Projects, peers, passion, play. In *Constructionism and creativity: Proceedings of the third international constructionism conference. Austrian computer society, Vienna.* 13–20.

[78] Mitchel Resnick. 2017. *Lifelong kindergarten: Cultivating creativity through projects, passion, peers, and play.* MIT press.

[79] Francisco Javier Sandoval-Henríquez, Fabiola Sáez-Delgado, and Maria Graciela Badilla-Quintana. 2025. Systematic review on the integration of immersive technologies to improve learning in primary education. *Journal of Computers in Education* 12, 2 (2025), 477–502.

[80] Savage Interactive. 2024. Procreate Handbook: Video. https://help.procreate.com/procreate/handbook/actions/actions-video. Accessed: 2024-05-21.

[81] Maggi Savin-Baden, Zak Savin-Baden, and C H Major. 2026. Fostering a deep approach to learning through integrating XR and Maker Education. *Innovations in Education and Teaching International* 0, 0 (2026), 1–17. doi:10.1080/14703297.2026.2628006

[82] Laura Scheepmaker, Kay Kender, Christopher Frauenberger, and Geraldine Fitzpatrick. 2021. Leaving the Field: Designing a Socio-Material Toolkit for Teachers to Continue to Design Technology with Children. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 145, 14 pages. doi:10.1145/3411764.3445462

[83] Joschua Thomas Simon-Liedtke and Rigmor C Baraas. 2022. The Need for Universal Design of eXtended Reality (XR) Technology in Primary and Secondary Education. In *Virtual, Augmented and Mixed Reality: Applications in Education, Aviation and Industry*, Jessie Y C Chen and Gino Fragomeni (Eds.). Springer International Publishing, Cham, 121–141.

[84] Casey Smith and Mike Tissenbaum. 2025. REACH: Extending reality for distributed collaborative making. *Computers & Education: X Reality* 7 (2025), 100111. doi:10.1016/j.cexr.2025.100111

[85] Annalisa Soncini, Emilio Paolo Visintin, Maria Cristina Matteucci, Carlo Tomasetto, and Fabrizio Butera. 2022. Positive error climate promotes learning outcomes through students' adaptive reactions towards errors. *Learning and Instruction* 80 (2022), 101627.

[86] Gary S. Stager. 2013. Papert's prison fab lab: implications for the maker movement and education design. In *Proceedings of the 12th International Conference on Interaction Design and Children* (New York, New York, USA) *(IDC '13)*. Association for Computing Machinery, New York, NY, USA, 487–490. doi:10.1145/2485760.2485811

[87] Nick Taylor, Keith Cheverst, Peter Wright, and Patrick Olivier. 2013. Leaving the wild: lessons from community technology handovers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 1549–1558. doi:10.1145/2470654.2466206

[88] Eric J. Topol. 2019. *The Topol Review: Preparing the healthcare workforce to deliver the digital future.* Independent Report. Health Education England, London, UK. https://topol.digitalacademy.nhs.uk/the-topol-review Commissioned by the Secretary of State for Health and Social Care.

[89] Mucella Ulug, Melis Seray Ozden, and Ahu Eryilmaz. 2011. The effects of teachers' attitudes on students' personality and performance. *Procedia-Social and Behavioral Sciences* 30 (2011), 738–742.

[90] Maarten Van Mechelen, Rachel Charlotte Smith, Marie-Monique Schaper, Mariana Tamashiro, Karl-Emil Bilstrup, Mille Lunding, Marianne Graves Petersen, and Ole Sejer Iversen. 2023. Emerging Technologies in K–12 Education: A Future HCI Research Agenda. *ACM Trans. Comput.-Hum. Interact.* 30, 3, Article 47 (June 2023), 40 pages. doi:10.1145/3569897

[91] Parminder Varma, Shivinder Nijjer, Kiran Sood, Simon Grima, and Ramona Rupeika-Apoga. 2022. Thematic analysis of financial technology (Fintech) influence on the banking industry. *Risks* 10, 10 (2022), 186.

[92] Megan Venn-Wycherley, Ahmed Kharrufa, Susan Lechelt, Rebecca Nicholson, Kate Howland, Abrar Almjally, Anthony Trory, and Vidya Sarangapani. 2024. The Realities of Evaluating Educational Technology in School Settings. *ACM Trans. Comput.-Hum. Interact.* 31, 2, Article 26 (Feb. 2024), 33 pages. doi:10.1145/3635146

[93] Nathaniel Von der Embse, Dane Jester, Devlina Roy, and James Post. 2018. Test anxiety effects, predictors, and correlates: A 30-year meta-analytic review. *Journal of affective disorders* 227 (2018), 483–493.

[94] Stacey Waters, Leanne Lester, and Donna Cross. 2014. How does support from peers compare with support from adults as students transition to secondary school? *Journal of Adolescent Health* 54, 5 (2014), 543–549.

[95] Hajar Zekeik, Mohamed Chahbi, Mohammed Lamarti Sefian, and Imane Bakkali. 2025. Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. *EURASIA Journal of Mathematics, Science and Technology Education* 21, 9 (2025), em2699.