Integrating Art and Creative Thinking Into STEM

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Abstract: *In the context of rapidly evolving educational technologies, STEAM approaches have become increasingly important for fostering creativity, critical thinking, and technological literacy. This paper presents an innovative STEAM-based educational activity that reverses the conventional 3D design workflow. Instead of starting with digital modelling, learners begin by physically creating objects from playdough, which are then digitized using 3D scanning, processed via slicing software, and finally 3D printed. This "hands-on-first" approach fosters creativity, spatial reasoning, and digital fluency by bridging tactile exploration with technological skills. Ways of applying world-wide teamwork and/or business-exploitable outputs are demonstrated. The activity is pedagogically grounded in the 5E Inquiry-Based Learning Model and Bruner's theory of representation, supporting learning transitions from enactive to iconic and symbolic modes. Designed primarily for pre-service teachers, the activity enables them to formulate engaging, meaningful tasks that integrate science, technology, engineering, arts, and mathematics for primary education contexts. By highlighting the shift from formalism to learner-driven creativity, the paper argues that STEAM education should not only prepare students for technological literacy but also empower them to express, create, and think critically. The novelty of reversing the typical digital-to-physical process positions this method as a compelling contribution to future-ready education.*

1. Introduction

In today's rapidly evolving digital world, education must address not only technological innovation but also foster the expansion of human capacity for creativity, critical thinking, and meaningful engagement. Although automation and artificial intelligence (AI) are becoming increasingly pervasive, reducing the need for certain routine skills, the ability to think creatively and act adaptively remains essential. While some believe that the rise of AI and automation might diminish the relevance of hands-on learning or problem-solving, we argue instead that these very trends amplify the need for educational approaches that develop holistic, transferable competencies.

One promising response to these challenges is the integration of arts into STEM, forming the interdisciplinary STEAM framework (Science, Technology, Engineering, Arts, and Mathematics). STEAM not only expands the epistemological base of STEM by including the arts but also enables educators to design activities that promote curiosity, imagination, and critical reflection [1, 2]. Research increasingly confirms that such integration supports learner motivation and engagement by aligning technical competencies with personal expression and creativity [3, 4].

In this article, we present a theoretically grounded design of a STEAM learning activity that connects physical modelling (playdough), digital fabrication (3D scanning and printing), and creativity-oriented problem-solving. Unlike conventional workflows that begin with digital modelling, our approach reverses the sequence by starting with tangible, hands-on creation before transitioning to digital representation and fabrication. This inversion of the process emphasises sensory exploration and imagination as the starting point for technological engagement. Rooted in constructivist and inquiry-based learning approaches, the activity is aimed at pre-service primary teachers and children in early education. It supports both digital and physical exploration, while encouraging learners to design meaningful artefacts.

Integrating 3D modelling and printing in teacher education can foster the Four C's – Creativity, Critical Thinking, Collaboration, and Communication – in a gender-inclusive manner [5], emphasising the need for STEAM activities that promote both technical skills and inclusivity, motivation, and creative confidence.

In the following sections, we first outline the theoretical background supporting the integration of artistic and creative thinking into STEAM. We then describe our proposed learning activity in detail and discuss its potential for teacher education and early learners. Finally, we reflect on the broader pedagogical implications of such creative-technological fusion.

2. Theoretical Background

To support the integration of creativity, manual modelling, and digital fabrication into meaningful STEAM learning, our design draws on several interconnected theoretical perspectives.

2.1. Inquiry-Based Learning and the 5E Model

A key pedagogical framework underpinning the proposed activity is the 5E instructional model: *Engage*, *Explore*, *Explain*, *Elaborate*, and *Evaluate*. Originally developed to foster inquiry in science education, the 5E model has also proven effective in STEAM contexts, particularly when learners construct knowledge through cycles of observation, experimentation, and reflection [6]. The stages of our activity – from playful modelling to the production of digitally printed artefacts – correspond to each phase of the 5E cycle, offering a structured yet open-ended environment for exploration and meaning-making.

2.2. Constructivism and Bruner's Modes of Representation

The activity also reflects Bruner's theory of cognitive development [7], particularly his three modes of representation: *enactive* (action-based), *iconic* (image-based), and *symbolic* (language/formula-based). In our approach to 3D modelling and printing, these modes manifest as follows: beginning with physical modelling (*enactive*), transitioning to digital representation (*iconic*), and culminating in verbal reflection or mathematical interpretation (*symbolic*). This progression enables learners to traverse multiple layers of understanding, thereby enhancing both spatial reasoning and conceptual flexibility. Importantly, this representational shift does not only support general cognitive development but also scaffolds mathematical thinking, as learners move from embodied exploration of symmetry and proportion toward abstract reasoning about geometric structures.

2.3. Project-Based Learning and Real-World Relevance

Problem-based and project-based learning (PBL) approaches are central to our design, as they promote learner autonomy and practical engagement [8]. The core task – designing an original playdough model and transforming it into a 3D-printed artefact – mirrors authentic engineering and design cycles. This fosters learner agency, iterative thinking, and skills crucial for success in 21st-century contexts.

2.4. Transdisciplinary Thinking and the Role of the Arts

STEAM education, especially in its transdisciplinary form [3], promotes a holistic synthesis across disciplines. In our activity, the artistic component is not an add-on, but a catalyst for innovation and emotional engagement. It stimulates imaginative risk-taking and personal expression, encouraging learners to challenge conventional problem-solving boundaries. Moreover, integrating the arts helps bridge cognitive and affective domains, contributing to deeper engagement and creativity [2].

2.5. Creativity and the Four C's

Consistent with frameworks such as the Four C's – creativity, critical thinking, communication, and collaboration – and supported by research demonstrating the potential of 3D modelling and printing to foster these competences in education [5], our activity deliberately creates opportunities for creative construction, dialogue, and collaborative reflection. These competences emerge as integrated outcomes of well-designed, student-driven learning environments that blend manual and digital expression.

2.6. Learner Diversity and Digital Literacy

Finally, our approach recognises the needs of today's learners – often referred to as *digital natives* [9] – who are accustomed to interactive, technology-rich environments. However, native familiarity does not necessarily equate to critical or productive digital skills. The transition from playdough modelling to 3D printing engages learners in both intuitive and formal dimensions of technology use, framing digital literacy as a creative and intellectual competence rather than merely a technical skill.

3. Educational Approach: Bridging Creativity and Technology

The proposed activities stem from the current needs to modernise teacher education by integrating digital competencies with creative, hands-on pedagogical strategies. We focus on pre-service primary school teachers, aiming to equip them with tools and mindsets that enable them to bridge abstract curricular goals with engaging, multimodal experiences for young learners.

The global roof for all above concepts is the problem-based learning (PBL). This label encompasses a broad range of practices – from teacher-guided inquiry to open-ended exploration [10] – in our context, PBL primarily serves as a platform for designing tasks that promote *playful experimentation, critical thinking, and artistic expression* in STEAM domains. Our goal is not only to foster these qualities in children, but also to prepare future teachers to be *creative facilitators* of learning.

The activities themselves combine manual modelling (playdough), digital scanning, 3D modelling, and 3D printing, thereby connecting tactile engagement with digital literacy. This process naturally supports constructivist principles and aligns with the 5E Inquiry Model [6], where learners:

- *Engage* through sensory play,
- *Explore* materials and shapes hands-on,
- *Explain* through discussion and digital modelling,
- *Elaborate* by refining models and integrating new tools (e.g. Tinkercad, GeoGebra),
- and finally *Evaluate* by presenting and reflecting on their artefacts.

In this sense, the art's main role is not merely decorative, but it becomes a vehicle for inquiry, communication, and design thinking. The activity allows for multiple individual entry points and learner choices. Such an approach is crucial for fostering the Four C's of 21st-century education: *Creativity, Critical Thinking, Collaboration, and Communication* [5]. Moreover, the digital output can serve as a basis for broader interdisciplinary integration, including social, cultural, or environmental themes.

While some argue that advanced technologies like AI and automation make traditional skills obsolete [11], we argue the opposite: such developments necessitate *even stronger pedagogical links* between human creativity and technological fluency. By engaging all teachers in this kind of task, we help them critically reflect on what it means to learn, to create, and to teach in digitally enhanced educational environments.

4. Activity Implementation: From Physical to Digital and Back Again

One of the core innovations of the presented educational approach lies in reverting the usual 3D design process. While traditional STEAM activities mostly begin with the creation of a digital model – using software like Tinkercad or Fusion 360 – and then they proceed to 3D printing, our approach proposes the opposite. It starts with a physical artefact, manually shaped by learners from playdough, and only afterwards transitions into the digital space via 3D scanning.

This novelty not only moves children's tangible creativity to the very beginning of the design process, but it also invites them to explore the physical properties of shapes and materials before engaging into a more abstract and technical world of digital modelling. This workflow encourages imagination, trial and error, and spontaneous expression through manual work attributes often absent in pre-digital design stages.

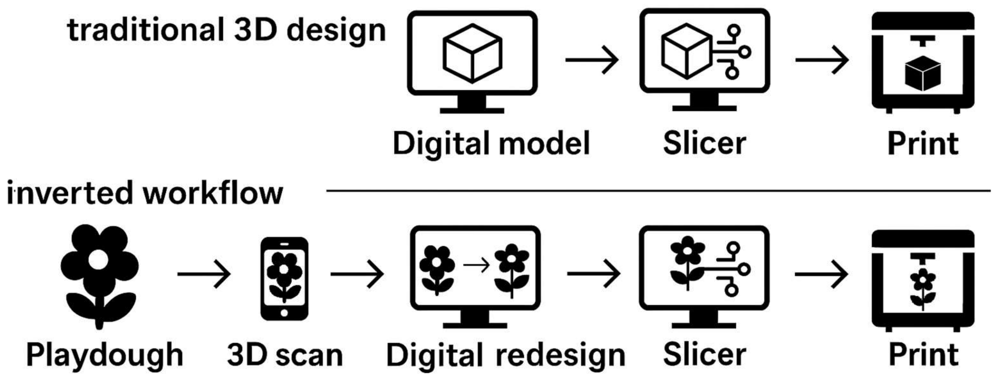

Figure 4.1 Inverted workflow compared to traditional 3D design

This diagram (Figure 4.1) highlights the innovative reversal in the creative process: rather than beginning with digital design software, the activity starts with hands-on sculpting using playdough. This approach not only enhances learner engagement but also aligns with the pedagogical goals of fostering creativity and connecting physical intuition with digital processes.

Step-by-Step Activity Overview

- **Step 1: Manual modelling with playdough**

Pupils are encouraged to design a creative object using playdough. In our pilot version, the theme was *"My Favourite Flower"*. This phase focuses on tactile exploration, shape construction, and fine motor skills development.

- **Step 2: 3D scanning**

Using a mobile application capable of 3D scanning, learners capture the physical object and convert it into a digital STL file. This moment represents a crucial educational transition – from physical to digital. It makes the students capable of visualising their artefacts in 3D space and of comprehending basic principles of three-dimensional geometrical representation including additional concepts like symmetry and volume. This stage introduces students to basic mathematical principles, such as symmetry, rotation, scaling, and three-dimensional geometric representation, making mathematics an integral part of the creative workflow.

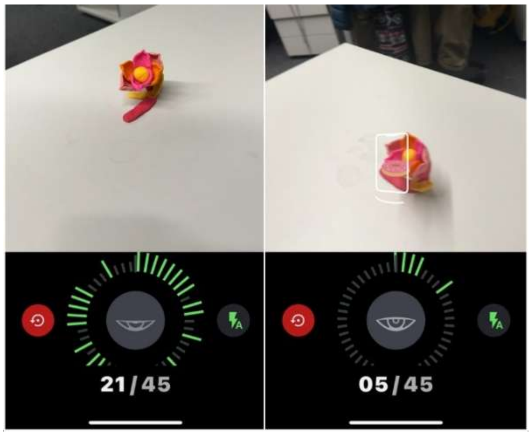

Figure 4.2 3D scanning by iPhone with a 3D scanning app

Optionally, the obtained STL file can be imported into a digital modelling environment (e.g., Tinkercad), where students can further refine, edit, or enhance their designs. This intermediate step expands the learning potential by introducing digital editing workflows and supporting deeper engagement with the geometry and structure of their creations.

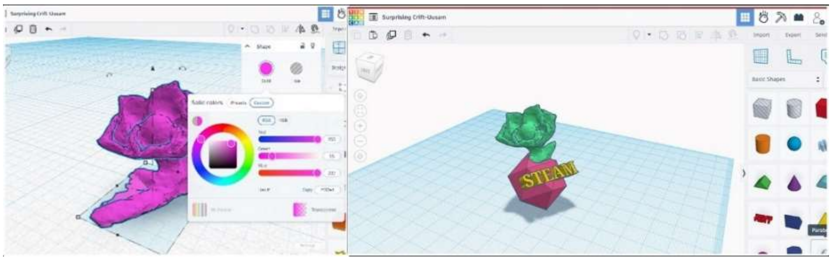

Figure 4.3 Redesign in Tinkercad

- **Step 3: Preparing for 3D printing**

In a slicing program, pupils or teachers adjust the object's size, fill density, and orientation, and generate the G-code file for printing. This stage introduces the learners to digital manufacturing processes and technological reasoning and decision-making.

Figure 4.4 G-code file preparing in slicing software

- **Step 4: 3D printing and creative variation**

The final 3D product can be printed in various colours and sizes according to student preferences and aims. The diversity of the outputs illustrates both the flexibility of digital technologies and the richness of learner imagination. The learners can also combine their individual templates and create repetitive patterns, mirrored bodies or (as a group) compose their individual pieces to complex structures. They can study how to do the same "composing tricks" in the 3D virtual space and in the reality with their partial outcomes. They can even design locking mechanisms which (added to their objects in the 3D virtual reality) allow to produce "infinite" chains allowing everyone to become a co-producer.

Figure 4.5 Printed objects

- **Step 5 (Potential): 3D printing as a massive production**

This hands-on-to-high-tech pipeline empowers pupils not only to create, but also to redesign and reimagine their initial outcomes and to refine their design. Finally, they also can transform their artistic ideas into reproducible artefacts and produce them massively – thus bridging their manual, digital, technological and business literacy in one coherent learning flow. STEAM education should be interdisciplinary. The Step 5 goes beyond the traditional STEAM by incorporating Business and Economy into the package.

Learning Opportunities and Pedagogical Benefits

- The activity supports constructivist learning by allowing learners to construct meaning through hands-on experience and reflective digital engagement.
- It introduces design thinking and iterative processes, as students can rescan, resize, or reprint with modifications.
- It is highly adaptable to various themes and subjects across STEAM disciplines.
- The integration of mobile technology and low-cost 3D scanning opens accessibility and promotes digital literacy from early school years.
- Creative variations in printing foster aesthetic sensitivity and artistic decision-making, aligned with the "A" in STEAM.
- It allows making the 3D printing a team activity – including even virtual worldwide teams.

5. Pedagogical Implications and Theoretical Anchoring

From a mathematical education perspective, the activity provides opportunities to strengthen foundational geometric concepts. Learners engage with symmetry, proportion, measurement, scaling, and geometric decomposition while working across physical and digital media. These competencies are not taught in isolation but emerge naturally from the creative process, making mathematical learning more meaningful and contextualized.

5.1. Beyond Formalism: Learning through Meaningful Creation

Traditional approaches to mathematics and science education have often emphasised abstract formalism, rule-based procedures, and symbolic manipulation. While these practices remain essential for developing procedural fluency and logical reasoning, they often fall short when it comes to fostering intrinsic motivation, creativity, and practical understanding. Our proposed activities respond to this limitation by grounding learning in *tangible artefact creation, personal meaning-making* and *team collaboration*.

As pointed out in [9], Digital Age learners – so-called "digital natives" – are accustomed to interactive, fast-paced, and visual learning environments. However, they also benefit from tactile, physical experiences that stimulate multiple cognitive pathways. By integrating hands-on playdough modelling with digital scanning and fabrication technologies, this learning scenario provides a *dual-modal learning experience* that bridges abstract reasoning with concrete manipulation.

This approach aligns with Bruner's theory of representational development [7], which distinguishes between enactive, iconic, and symbolic representations. The activity begins inactively (physical shaping of playdough), moves through iconic stages (3D scans and visual representations), and culminates in symbolic outputs (digital files, printed artefacts, coding parameters). Notice that the word "symbolic" here gets a wider meaning than in the formal, standard mathematics. It may include both formal and physical outputs of the process. As a result, learners navigate through all three cognitive levels in a seamless and natural way.

Furthermore, one can easily observe how the boundaries of science, technology and mathematics can be *productively transgressed* through creative thinking. As notes in [3], the shift from interdisciplinary to transdisciplinary teaching in STEAM allows for richer, more connected experiences. Rather than seeing disciplines as silos, this educational approach encourages learners to perceive *design, problem-solving, aesthetics and mathematics as interrelated components* of an integrated learning process.

Thus, the pedagogical implications of this activity reach beyond the acquisition of digital skills. They contribute to a creative agency, collaboration, and cognitive flexibility, which are core pillars of both the 4C model and the 21st century skills framework [5]. Such competencies are vital for addressing future challenges in a complex, technology-driven world.

5.2. Bruner's Representational Modes in Practice: From Clay to Code

One of the most pedagogically significant aspects of the described activity is how it naturally guides learners through Jerome Bruner's theory of representational development [7], according to which conceptual understanding is built through three progressive modes:

- **Enactive** (learning through action),
- **Iconic** (learning through images),
- **Symbolic** (learning through abstract symbols).

This activity seamlessly incorporates all three, following a progression that mirrors Bruner's framework. Students move from physically creating a shape with their hands (enactive), to visualizing it digitally (iconic), and finally to abstract manipulation through digital slicing and machine language (symbolic). This process can be visualized as follows:

Table 5.1 Learning Trajectory through Bruner's Representational Modes

Bruner's Mode	Activity Stage	Description
Enactive	Moulding the object from playdough	Tactile interaction, motor skills, and kinesthetic understanding.
Iconic	3D scanning and on-screen manipulation	Visual-spatial recognition of forms, rotation, and proportions.
Symbolic	Slicing and preparing the G-code	Abstract processing of shapes into numerical and procedural instructions.

This transition is not externally imposed but emerges organically as learners engage with each phase. The pedagogical strength lies in the fluidity of this representational shift: it allows students to experience and internalize the connection between physical artefacts, visualization, and abstract coding without needing formal instruction in each domain.

As such, this activity is not only innovative in its technological approach, but also cognitively grounded, offering an inclusive learning trajectory aligned with developmental learning theories.

5.3. Pedagogical Anchoring in the 5E Inquiry-Based Learning Model

To further situate the activity within an established educational framework, we draw upon the 5E Model of Inquiry-Based Learning [6], which structures learning into five phases: Engage, Explore, Explain, Elaborate, and Evaluate. This model is widely used in science education and STEAM contexts to support active, inquiry-driven learning.

The flower activity described above maps naturally onto these phases:

Table 5.2 5E Model Activity Table

5E Phase	Activity Component	Learning Focus	Skills & Knowledge
Engage	Observing natural flowers; discussing shapes, colours, and structures	Stimulating curiosity; activating prior knowledge	Visual observation, pattern recognition, communication skills, vocabulary activation
Explore	Modelling with playdough; experimenting with shapes and dimensions	Hands-on experimentation; open-ended creative exploration	Fine motor skills, spatial reasoning, creative thinking, geometric construction and symmetry, tactile engagement
Explain	3D scanning and viewing the digital model; comparing with the physical model	Connecting physical and digital representations; understanding form	Digital literacy, geometric abstraction, scale and proportion, interpretation of digital artefacts
Elaborate	Slicing the model and printing variations; discussing scale, function, and colours	Applying technical knowledge; refining design decisions	Technical literacy, use of slicing software, iterative design thinking, linking form and function, geometric transformations
Evaluate	Reflecting on process and printed results; peer discussion and self-assessment	Critical thinking and communication of outcomes	Self-assessment, analytical comparison, articulation of learning, peer feedback skills

This inquiry cycle gives structure to what might appear to be a free-form creative process, ensuring that both procedural skills (e.g., working with software, handling materials) and conceptual knowledge (e.g., symmetry, form, scale, digital representation) are systematically developed. The addition of clearly articulated learning outcomes for each phase further reinforces the pedagogical value of the activity and provides a concrete foundation for its implementation in teacher education contexts, consistent with the broader principles of inquiry-oriented teaching in technical and STEAM education [12].

6. Discussion and Reflection

The presented activities illustrate a meaningful shift in how creative and technological processes can be intertwined in early STEAM education. By reversing the typical sequence of 3D printing – from digital design to physical output – the project initiates learning in the tangible, sensory-rich world of manual modelling. This change is not only procedural but epistemological: learners begin with a concrete, embodied experience and only subsequently abstract their models into digital forms. In this way, this educational approach reinforces Bruner's notion of the enactive and iconic representations as prerequisites for symbolic understanding [7].

Such an approach challenges the formalised and often decontextualised nature of traditional science and mathematics education. Rather than starting with symbolic abstractions and algorithms, students work with materials that are physically manipulable and intuitively meaningful. Their ideas are shaped not just by theoretical reasoning but by hand–eye coordination, trial-and-error, visual judgement, and tactile perception.

Our approach supports the position of scholars who argue that scientific knowledge is not purely theoretical, but is shaped by material tools, sensory experience, and creative exploration [1, 4]. It resonates with the shift from STEM to STEAM, incorporating the role of artistic and creative domains in meaning-making. One can even consider adding another meaning to E: economy and business.

Moreover, this activity highlights the relevance of common sense, intuition, and imagination in problem-solving. Echoing Hvorecký's critique of over-formalised instruction [13], the project shows that productive learning emerges not from rigid application of formulas but from playful experimentation and reflective iteration.

Importantly, learners not only understand the process – they *own* it. They become capable of transferring their idea across media, scaling their outputs, and exploring their aesthetic variations. These are not trivial technicalities – they can serve as signs of deeper cognitive control and creative agency.

From a motivational perspective, the workflow empowers students. It is inclusive of different learning styles and talents, invites personal expression, and produces visible outcomes – factors known to enhance engagement and confidence, especially among younger learners [2, 3]. Students do not simply *consume* digital tools – they become active designers and creators of hybrid artefacts that blend imagination, mathematics, and technology.

7. Conclusion

This paper has presented a pedagogically grounded and creatively rich activity that merges physical modelling with digital technologies applying a reversed 3D printing workflow. By starting with playdough and guiding students through scanning, slicing, and printing, the activity exemplifies how embodied, sensory experiences can serve as a foundation for developing spatial reasoning, technological fluency, and artistic expression within STEAM education.

The novelty of this approach lies in reversing the usual direction of the design process: from hands-on creation to digital modelling, rather than vice versa. This shift not only supports multimodal learning and creativity but also encourages children to see their ideas materialize in tangible, meaningful ways. It empowers learners by valuing their intuitive knowledge and enabling iterative design thinking.

The theoretical framework of the 5E Inquiry Model [6], combined with Bruner's modes of representation [7], provides a robust pedagogical basis for the activity. It supports cognitive development across physical, visual, and symbolic domains, aligning with contemporary constructivist and interdisciplinary learning paradigms. Moreover, this approach addresses the growing need to humanize technology education by embracing artistic expression, collaboration, and problem-solving as equally vital dimensions of future-ready education.

By designing such activities for future primary school teachers, we aim to foster their competence and confidence in creating integrated, inquiry-based STEAM lessons that are inclusive, engaging, and grounded in real-world processes. The findings and reflections shared here offer valuable insights for educators, curriculum designers, and researchers interested in bridging creative expression and technological fluency in early education.

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