A new approach in the making: reinvigorating engineering education in UK schools

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Abstract:

The value of Science, Technology, Engineering, Arts and Mathematics (STEAM) education, for STEM subjects and for developing the outcomes desired of a broader education, has seen significant interest in recent years. In the UK educational pathways into engineering are limited and engineering is rarely mentioned in the curriculum. Its closest partner, Design Technology, is typically under-resourced, especially in primary schools. However, the perceived value of STEAM in primary education has led to a range of different initiatives which have made this a fertile testbed for new approaches; approaches which will, over the coming decade, filter through all phases of education. Critically, STEAM has been identified, through its fusion with the arts, as fostering creative thinking in ways useful to STEM, particularly engineering. Additionally, it is argued that STEAM, if implemented early enough, can diversify the range of individuals considering careers in engineering.

We draw on a five-year, primary education arts-engineering project which showed the efficacy of this inquiry-based STEAM approach in developing confident, creative learners, who felt they had agency in their learning, and a further two-year project working with teachers to design innovative art-engineering schemes of work following this model. The research explores the views of the engineers/designers, teachers, artists and pupils.

The model developed from the research, the Trowsdale Art-Making Model for Education, has been tested by teachers as a practical approach to designing more embodied and inquiry-based curricula and pedagogies. The engineers identified this as critical in fostering children's interest for and their ability in engineering.

Keywords: TAME, Imagineerium, compulsory education, Design Technology, STEAM

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1. INTRODUCTION

A team of artists and engineers jointly conceived an aspiration to educate, enthuse and support Coventry's children to develop as imaginative engineers. This followed a history of collaborations on outdoor arts projects, particularly the design and build of a 6-metre mechanised 'Godiva' puppet for the 2012 Cultural Olympics. In part this educational initiative was driven by a desire to support local children growing up in a largely post-industrial city with a strong engineering heritage, and in part by the recognition by engineering companies that in an ever-increasing global market they need to ensure a supply of young people to take up apprenticeships in the future.

The resulting *educational project*, *The Imagineerium*, was a 10-week intervention working with children in Key Stage 2 (9-10 years olds) in up to 5 schools a year, for 5 years. Over this period, *The Imagineerium* worked with 21 schools and over 500 children. A legacy project, *Teach-Make,* which supports teachers to develop *Imagineerium-like* curricula and practices in their schools, is completing its first iteration in 7 schools. These curricula are primarily related to Design Technology. A second iteration is planned with 13 school in 2023.

In this brief paper, we give an overview of this distinctive 'art-making' approach; a particular type of STEAM (Science, Technology, Engineering, Arts and Mathematics) education. It builds upon inquiry and project-based models to integrate art-making and engineering in ways that children and their teachers recognise as developing an interest and thirst for design activities but also has a positive impact on more global educational outcomes (Trowsdale, 2017, 2020; Trowsdale, McKenna and Francis, 2019, 2021). The model has been consolidated as The Trowsdale Art-making Model for Education (TAME), see figure 1.

Figure 1 Key components of the TAME approach to Education.

We briefly set out the experience of *The Imagineerium* and the research evidence that clarified its key components, and give insights into the advantages of this approach. We discuss the key characteristics of the TAME before finally reporting on the impact the approach has had on teachers' practices in the *Teach-Make* project. We begin, however, with an outline introduction to STEAM education, to which *The Imagineerium* was initially aligned.

2. STEAM EDUCATION

STEAM education has received much critical attention in recent years, largely as a response to perceived deficits in STEM (Science, Technology, Engineering and Mathematics) education (see, for example, Burnard et al, 2021; Carter et al, 2021; Colucci-Gray et al, 2017; Guyotte et al, 2014; Miah, 2021). The nature of these deficits and the best way to overcome them, however, is a matter of much contention (Mejias et al., 2021). For some the issue is a lack of breadth that the dominance of STEM education has engendered in the school curriculum. We have, in addition, argued that adequate preparation in STEM subjects benefits from an integration with ideas and practices from the arts (Davies and Trowsdale, 2021). In forthcoming work, we focus on engineering as an essentially transdisciplinary practice where the disciplinary perspectives of the sciences, arts and humanities are all pertinent and their interdependency is significant to learning (also see higher education examples in Ertas et al., 2003; Wognum et al., 2018). *The Imagineerium*, emerging from the work of engineers and artists, was conceived as an arts-engineering integrated educational intervention, though given the UK primary/elementary school context (where engineering is not a discrete subject) it was aligned to national standards in science, design technology and mathematics.

3. *THE IMAGINEERIUM*

Imagineer, a cultural organisation who work with communities and professionals in developing outdoor arts, have a history of collaboration with local engineering companies, and with the active involvement of senior leaders in those companies. In 2013, this partnership proposed a 10-week educational intervention to engage children in imaginative engineering (imagineering). Children were positioned as 'imagineers' commissioned alongside adult artists and engineers to design and prototype a mechanised, kinetic, artwork. These designs were developed in groups and the winning design from each school was built full scale by one of the engineering companies involved. The actual commissions changed each year, but included developing cycle-powered performance 'floats' as part of a Coventry Festival of Imagineers, and developing moving sculptures for installation in a new heritage park in the city. The commissions were therefore 'real world' and there was a sense amongst children of the importance of their work to their locality, communities and the wider world. The project was shaped by the kind of design processes that the engineers and artists involved had deployed in their earlier professional collaborations, where a phase of 'possibility thinking' and the exploration of ideas with a broader range of stakeholders led to a more focussed designing of a product suitable for their purposes. It was also shaped by a series of 'imagineering behaviours' which drew from Trowsdale's analysis of imagineers' practice through an arts and creative learning lens (Trowsdale, 2020) and from models of engineering habits of mind (Lucas et al., 2014).

The team who conceived of *The Imagineerium* had worked with Trowsdale and invited her to contribute to the project and research it – initially for one year, but eventually this led to a five-year research project (Trowsdale, 2020). Each year, children and teachers participated in the research which used a range of qualitative and quantitative instruments. Interviews were conducted with pupils, teachers, artists and engineers before and after *The Imagineerium*, and with pupils, 12 months after. Pupils and teachers also completed questionnaires accessing pupils' confidence in learning (in general) and particularly in design technology and science (see Trowsdale, McKenna and Francis, 2019, 2021 for more details of the instruments used). There were also a series of participant observations conducted by researchers (see Trowsdale, 2020). Ethical approval was granted by University of Warwick ethics committee. As noted previously, the research has been reported elsewhere and shows a suite of positive educational outcomes for children. These include a quantifiable sense of greater confidence in sciences and being creative (as rated by both children and teachers), a stronger sense of collaboration, and greater interest in future creative engineering projects. In girls, the latter response was persistent, showing up in interviews conducted 12 months after the intervention.

A significant outcome of the study was the need to model the intervention, establish the key characteristics that gave rise to these positive outcomes and how this type of project could be embedded in a school's regular curriculum. The present iteration of this modelling process is the TAME.

4. *THE TAME*

Two overriding characteristics emerged from the data. The first was that the intervention was focused on commissioning children in a real-world task that they could relate to, were motivated by and which focussed their attention. The commissions in *The Imagineerium* were all part of local events and projects, were open-ended, required the children to explore different possible ways they could meet the commission and enabled children to take different educational routes to develop the necessary knowledge and skills they would require. The second is that children were commissioned into a particular type of community, a community of imagineers. Drawing on Heathcote's (Heathcote and Bolton, 1995) 'mantle of the expert', the children were commissioned *as if* imagineers, which is both an imagined and a real framing. It was imagined in that they lacked the skills and experiences of the adult imagineers (in arts and engineering) and needed guidance and support; yet it was real in that they were expected to aspire to the behaviour of imagineers and to *seriously* pursue the design of the commission. The term 'seriously' here references such educational practices as *serious games* where students are expected to engage in a playful context to achieve positive educational outcomes (see, for example, Vekiri et al., 2022). Each year, the children entered a pre-existing community of adult imagineers, who embodied what being a member meant as well as reinforcing both tacitly and explicitly the kinds of behaviours that were expected. In the development of the model beyond *The Imagineerium*, there has been a shift in language with the term 'imagineer' being replaced and developed into 'art-maker' or 'maker' who are part of a community of practising *art-makers*.

The research also identified four further important aspects of *The Imagineerium*: the importance of active and embodied learning, the ways in which space was used differently (and thereby signalled particular behaviours), the ways knowledge was situated within the collective tasks, and the role of other adult art-makers in addition to teachers. Teacher and pupil interviews showed that these characteristics are rarely realised in the normal classroom experiences of children. Recent interviews for the *Teach-Make* project have shown that whilst teachers aspire to give these types of experiences, they feel restricted by the expectations of the school curriculum.

The TAME approach was conceptualised as reflecting a variety of different pre-existing models of education: inquiry-based (see Kelly, 2008; Eriksson and Lindberg, 2016), project-based (see Leat, 2017; Kokotsaki, Menzies, and Wiggins, 2016) and apprenticeship-like (see Lave and Wenger, 1991). This latter work shaped the understanding of the community as an art-making 'community of practice' with its three interrelated aspects of 'community', 'domain' and 'practice' (Wenger and Trayner, 2015). Although Lave and Wenger's work has been largely adopted in work with older learners, especially in relation to professional communities, the model accurately reflected the experience of children who became members of a pre-existing community of adults. This community of artists and engineers had a shared interest and competence in such work, had developed and continued to develop relationships with one another as part of their work, and had a shared repertoire of methods, knowledge, tools and stories which informed their practice. Lave and Wenger's (1991) conception of community of practice (CoP) emphasises a horizontal structuring of learning, and articulates a number of other features that made sense of children's experiences. Within CoPs different roles are available, children could, and did, at times choose to engage in different ways, reflecting Lave and Wenger's notion of 'legitimate peripheral participants' (Lave and Wenger, 1991:104). That is, they were both full members of the community and yet, in recognition of their novice and emergent status in relation to more expert members, at times were watching and witnessing. In this way they learnt from more expert members – who might be adults, or other children – in a variety of ways and not only by direct instruction. Children were able to see, understand and respect the skills and knowledge of others as these were used to further the design of their product. Further, when interviewed children consistently talked of activity in the terms 'we did…' when the observation data showed they had not been doing but had watched one of the adults doing it. This watching of skilled activity, and imaginatively re-living it in the first person, has been shown to be educatively valuable (see Rizzolatti, and Craighero, 2005).

Inquiry-based approaches in science education have had a mixed history in the UK, with a general view that encouraging children to explore the world often conflicts with efficient development of their knowledge of it. Evidence from *Teach-Make* teachers seems to reflect this position; a desire to encourage investigation is, in practice, curbed by the perceived demands of covering curriculum content. But inquiry-based approaches foreground a personal engagement with objects and ideas; playing and exploring in order to find out more about the world. Engineers involved in both projects have noted that such behaviours and familiarity with materials are important preconditions for successful design, for example through CAD. They also noted that this was a particular value of *The Imagineerium*, that children could explore the properties of materials and investigate what those materials could do. As the quotation below suggests, responding to a commission as part of a community of practising makers allowed children to develop the habit of exploring ideas and solving problems through materials.

> *I wanted to sort it out – not leave it… Since the project it has come to me that you need to keep on solving problems if something doesn't work… I just don't give up .. I feel more capable of doing it now.' (Pupil)*

The CoP provided a context which supported a disciplined approach to children's enquiry. Working alongside supportive, knowledgeable adults, who were using judicious questioning, helped the children to think through their ideas. Engineers involved in the project noted that they were learning how to do this from the artists involved, who seemed to be better placed to help children think rather than simply direct them to a possible answer. Comparisons of schools, some of whom added additional lessons in science, indicated no difference in children's knowledge between schools providing additional lessons and those who did not. Reviewing children's attainment during *The Imagineerium* seriously questions the assumption that inquiry-based approaches are less efficient (Davies and Trowsdale, 2021).

The importance of the focus on a particular project was also evident in the data, and this shaped the ways children were able to draw on the expertise of the adults in ways that they were able to see as meaningful in relation to the tasks they were undertaking. Learning was not general and context-free, but specifically related to children's design problems. However, as the quantitative data shows, children learnt about science, engineering, etc. and not just about the particular project. In part, this seemed to be because of the different ways in which adults represented new ideas. They used gesture, drawing, working directly with materials, as well as physical theatre – all naturally part of the ways those adults communicated with each other in this CoP. This diversity of ways of representing ideas appeared to help children to know in a deeper sense that was often achieved in their everyday education.

This foregrounded ways of working which were active and embodied. We can see this in both a superficial and more comprehensive sense. In a superficial sense, it was clear that the practice of art-making was active – members of the community stood up and were more mobile than would be expected in the normal classroom. They played with the materials and moved to work together in the same spaces. A key influencer on movement and activity was the different ways in which space was used. In classrooms, tables and chairs were pushed 'out of the way', outdoor spaces and school halls were used in order to 'create space' for children and adults to move and reconfigure furniture to suit the work they were doing. Visits to professional maker-spaces also featured and supported teachers' and children's thinking about how space could be used. At the more comprehensive level, there was evidence of the role of the body as a whole, rather than just the cognitive in learning (see Lakoff and Johnson, 1999). This was most keenly seen in the way children learnt about forces and how different cog systems and cams could be used *through* physical theatre. A senior director of a local engineering company, who was involved in *The Imagineerium*, commented on his realisation through the project of how 'the body is a piece of engineering', and that physical theatre fostered an easy way for children to 'discover the principles' and a deep level of understanding of engineering.

5. *TEACH-MAKE*

The current *Teach-Make* project has focussed on teacher development and supporting TAME approaches in schools. Each pair of teachers (both from one school) are commissioned to develop a distinctive scheme of work, usually focussed on the Design Technology aspects of the curriculum. They are supported through a series of development days and school specific learning groups facilitated by artists and engineers. The project is overseen by the present authors. The precise nature of the support was identified with the teachers involved and senior leaders at the schools, and has fallen into three categories: (1) support in understanding the TAME and the implications for curriculum design; (2) support for pedagogy, especially using physical theatre, drawing and storytelling more imaginatively and regularly in the classroom; and (3) Design Technology and Science content knowledge, including specific design solutions, using CAD and understanding the design processes used by engineers

Mid-project interviews with teachers identified their surprise at the impact of the TAME approach on children's learning. When asked to capture in a sentence the value for them, they reported:

> *'Creating a community of practice can lead to changes in children's behaviour as they rise to the expectations of the role allocated to them. Collaborative activities and projects allow greater independence of thought and ownership of their own learning' (Teacher 3)*

> *'Teach Make has given me the confidence to use a more physical and active approach by including movement in many areas of my teaching' (Teacher 12)*

6. *CONCLUSION*

There is a significant shortfall in Engineers in the UK, and we know that some social groups are poorly represented in the workforce. It is clear that girls, especially, are more likely to drop STEM subjects (and especially the physical sciences) at every possible point in their educational journey (see Francis et al., 2017; WISE, n.d.). In order to address these issues, we need educational interventions that impact early on, and which persist over time. There is a significant body of anecdotal evidence for the value of STEAM education to inspire children and young people, and that this includes a positive impact on marginalised social groups. The difficulty, as Colucci-Gray et al. (2017) and Mejias et al. (2021), amongst others, have noted, is that few of these STEAM projects are effectively evaluated nor, we would add, are they effectively modelled to assess their critically important characteristics.

The TAME has been evaluated to show that there are positive subject specific (STEM and arts) outcomes as well as more positive global learning outcomes. The model itself has also been developed to extend previous work in inquiry-based and project-based educational models. Most significantly, it has extended Lave and Wenger's work on CoPs into the education of children. The recent work with teachers, the *Teach-Make* project, has shown that this approach is manageable in school classrooms as part of their normal practice. Further work needs to be done, *in practice* by extending the research in other primary classrooms and into Key Stage 3 (11-14 year-olds), and *theoretically* by exploring measures for plotting children's increasing engagement in engineering.

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