Design and Technology Education: An International Journal

29.2

Design Thinking in Action: Fostering 21st Century Skills Alongside Subject Specific Knowledge at Key Stage 3 in D&T

Philip A. Jones, Liverpool John Moores University, UK

Abstract

This study explores the integration of Design Thinking into the Key Stage 3 Design and Technology (D&T) curriculum at a school in North-West England, focusing on fostering 21st-Century Skills alongside subject-specific knowledge. The research draws on a multiple case study approach derived from the 'Solving Genuine Problems for Authentic Users Project', which involves students aged 12-13. The paper critically examines the current educational emphasis on knowledge in England and the potential erosion of D&T's identity and scope within this framework. Through practical D&T activities rooted in Design Thinking principles, the study investigates how real-world problem-solving and innovation can be effectively embedded into early education to support students in tackling complex future challenges. The implementation of a Design Thinking Integrated Learning (DTIL) model is discussed, highlighting its capacity to engage students in empathetic, creative, and analytical processes that contrast with pervading approaches in D&T. The findings suggest that a balanced approach, integrating both knowledge and skills, is crucial for nurturing adaptable, competent learners capable of addressing the demands of the 21st-Century.

Keywords

21st-Century Skills, design thinking, constructivism, design and technology, pedagogy

The Evolution of 21st-Century Challenges

This paper extends the findings from a pilot study of the ‘Solving Genuine Problems for Authentic Users Project’ involving 12–13-year-old students at a school in the North-West of England (Jones, 2023). The pilot study was presented at PATT40, which prompted reflections on the study’s theoretical framework, methodology and methods. This paper presents a multiple case study of four subsequent projects undertaken by students at the same school.

In the contemporary context of rapid global change, the demand for the development of 21st-Century Skills has become increasingly crucial, including in education (Koh et al., 2015).

Technology extends and enhances human capabilities, ranging from simple tools such as a hand axe to advanced instruments such as a hadron collider. All technology amplifies human potential by either simplifying and accelerating processes or providing capabilities beyond natural human limits. In recent years, technological development has increased exponentially to the extent that it has outpaced human capabilities (Liu et al., 2024), highlighting a profound evolution in the tools at our disposal. This rapid technological progress, alongside the forces of globalisation, has fundamentally reshaped the nature of the workforce (Levy, 2010; Taylor et al., 2020), requiring individuals to possess a diverse skillset that goes beyond traditional academic knowledge. ‘Wicked’ problems (Buchanan, 1992; Rittel & Webber, 1973) such as

climate change, overpopulation, and rapid technological advancements have emerged, which are complex and 'messy' (Rittel & Webber, 1973), each demanding a diverse range of skills to manage successfully. Addressing the complexities of 21st-Century life and work demands that individuals are equipped with a set of specific skills, commonly known as soft or human skills. These skills are essential for successfully addressing the multifaceted challenges posed by rapid advancements in technology and societal changes (Poláková et al., 2023) that are affecting the world of work (McDiarmid & Zhao, 2023). The responsibility of ensuring individuals acquire these crucial skills falls on the education system (Koh et al., 2015; Liu et al., 2024), however it is argued that the educational models of the Industrial Age that pervade the current system are no longer adequate to equip students for such a future (MacDonald & Hursh, 2006; McDiarmid & Zhao, 2023; Petrillo et al., 2018).

While the skills that are often referred to as 21st-Century Skills are not new (Silva, 2008), they hold particular relevance today, given modern society's complexity, particularly the increasing role of technology in outsourcing work that humans do, such as machine learning and artificial intelligence (AI). Vital capabilities such as critical thinking and problem-solving have always been important and their need in education was first recognised by classical theorists such as John Dewey (Scardamalia & Bereiter, 2014); however in contemporary times, due to the emerging demands of knowledge-based economies, those capabilities are arguably more crucial now than they were before (Bereiter & Scardamalia, 2018; Rotherham & Willingham, 2009; Silva, 2008). UNESCO has explicitly emphasised that developing these skills should not be limited to higher-level students, and instead, it is deemed crucial to support all students in cultivating meta-cognitive competencies and skills from the very beginning of formal education (Scott, 2015). While there is a broad consensus on the need for 21st-Century Skills, there is debate on what constitutes these skills and there is a lack of universal definition (Joynes et al., 2019), which is evident in the many frameworks that have emerged globally to support educators in fostering the many skills deemed imperative in the 21st-Century.

Knowledge, Skills, and the Place of D&T

The framing of 21st-Century Skills as a construct in education could be described as a "crowded space" (Foster & Piacentini, 2023, p.9), with the use of differing terminology such as 21st-Century Skills, interdisciplinary skills, and soft skills, for example, creating ambiguity (Kelley et al., 2019; Miliou et al., 2023) . The term 'competencies' is often used interchangeably with 'skills', but it is also often considered in a broader sense as a set of skills, knowledge, and attitudes that, together, meet a complex demand (Ananiadou & Claro, 2009). There is no single prescribed approach to educating young people for the 21st Century (Scott, 2015), necessitating the development of many frameworks. A meta-analysis completed by Voogt and Robin (2012) identified a range of frameworks that were developed to define and guide the integration of 21st-Century Skills within education. A number of these frameworks have undergone several revisions since the authors' meta-analysis, and many have since ceased to develop any further. One such framework is the Assessment and Teaching of 21st-Century Skills (ATC21S), which focuses on ways to assess and teach skills such as critical thinking, problem-solving, collaboration, and digital literacy. It seeks to develop methods for educators to incorporate these skills into their teaching practices (Griffin & Care, 2015). Another framework is the OECD's Future of Education and Skills 2030. The OECD framework focuses on student well-being and agency, incorporating a range of cognitive, social-emotional, and physical skills. It also focuses on adaptability, problem-solving, and the ability to engage with others in a globally

interconnected world (OECD, 2019b). Of all the major frameworks available, the OECD framework has seen notable growth since its inception, with much ongoing research and development, however the P21 framework is more commonly referenced in the literature, especially in studies conducted in the USA.

The Partnership for 21st Century Skills (P21) framework outlines a blend of core subjects, life, and career skills, learning and innovation skills, and information, media, and technology skills. It also emphasises the importance of real-world context in learning (Battelle for Kids, 2019; P21, 2007). Within the P21 framework, the '4Cs' of creativity, critical thinking, communication, and collaboration are featured. The World Economic Forum (2015) produced a similar overarching model of 21st-Century Skills, featuring the 4Cs at the centre, suggesting the importance of these specific skills. The 4Cs have gained considerable attention within education and business (Kelley et al., 2019) and there has since been significant discourse on this aspect of the framework. The 4Cs provide a core concept that is both persuasive and easily targeted, which has been considered a pedagogically and policy-friendly model by large organisations and is also gaining some additional empirical validity (Thornhill-Miller et al., 2023). It is argued that the 4Cs can be seen as the highest-level transversal skills or 'meta-competencies' that allow individuals to maintain proficiency and continue developing their potential in a rapidly changing professional world (ibid.), making the 4Cs a suitable focus for this study.

The issue of skills and knowledge, whether one is more important, and indeed whether one is possible without the other has been debated across education for many years (Christodoulou, 2023). With the current emphasis on knowledge, there is a preference for direct instruction (Stockard et al., 2018). It is argued that direct instruction is best for knowledge transmission, modelling and demonstrating, however, is never sufficient on its own to ensure a deeper understanding of problem-solving, creativity or group work capacities (Desforges, 1995), therefore arguing the case for the enabling of skill development, especially those related to critical thinking. The discourse around skills and knowledge is vast and a lack of clear definitions for 'skill', 'knowledge' and 'competence' adds complexity, yet there is support for the argument that skill can be seen as the ability to retrieve knowledge and apply it to a task in a proficient manner (Lamri & Lubart, 2023). Skill can be conceptualised as "specific know-how that is pertinent to a given situation, resulting in the combination of knowledge" (Lamri & Lubart, 2023, p. 2) and other factors, emphasising that one cannot exist without the other. Skills versus knowledge could also be viewed as a false dichotomy, where knowledge forms the foundation for skill development (Christodoulou, 2023).

In the context of England's educational landscape, there is a notable shift towards a 'knowledge-rich' curriculum, as evidenced by the prominence of the English Baccalaureate (EBacc) in educational policy discourse (McLain et al., 2019). This movement appears to endorse a more traditional, knowledge-centric approach, potentially at the expense of creative and practical aspects of learning (McGarr & Lynch, 2017). The latest GCSE and A Level D&T Programmes of Study (DfE, 2015a, 2015b) reflect this shift, with a narrowed focus on exam-oriented content and less emphasis on creative coursework (Demetriou & Nicholl, 2022). This trend raises concerns about the erosion of D&T's identity (Spendlove, 2023a, 2023b) and its ability to foster a balanced set of skills within the curriculum.

Critics such as Demetriou and Nicholl (2022) argue that this reduced emphasis on imaginative and creative aspects in the curriculum could lead to a corresponding decline in these qualities amongst students. The current trend towards a 'knowledge curriculum', with its focus on academic achievement, presents a challenge to the development of broader human skills that are traditionally nurtured by constructivist and pragmatist educational approaches (Biesta, 2014; Hickman et al., 2009). This shift emphasises the need for a balanced educational model that values both academic knowledge and the development of practical, creative, and human-centred skills (Noweski et al., 2012; Razzouk & Shute, 2012; Scheer et al., 2012) – a balance that D&T is uniquely positioned to provide (Demetriou & Nicholl, 2022).

The D&T curriculum in England is ideally positioned to develop 21st-Century Skills, particularly in tackling contemporary societal challenges (Morrison-Love, 2022), by engaging students in contextual design and real-world problem-solving. While the subject possesses the potential to enable this sort of transformation, there is growing concern about the excessive focus on practical work in D&T at the expense of its educational and creative potential (de Vries, 2005; Nicholl et al., 2013; Nicholl & Spendlove, 2016). This focus contradicts the rigorous and innovative nature of D&T as envisioned in the English National Curriculum (DfE, 2013) and its GCSE and A Level Programmes of Study (DfE, 2015b, 2015a).

While increased subject matter has created challenges for teaching in all subjects in later key stages (Brown & Woods, 2022), it has been established that curriculum design at Key Stage 3 in D&T is a significant issue across England (Design and Technology Association, 2023), which contributes to the threat of continued decline of the subject. Practices have typically become focused on “routine practical tasks masquerading as design and make” (McLain, 2020, p. 79), with a distinct absence of creativity and authentic problem-solving (de Vries, 2005; Demetriou & Nicholl, 2022; Design and Technology Association, 2023; Nicholl et al., 2013; Nicholl & Spendlove, 2016; Rutland & Barlex, 2007), however, it should be noted that this does not apply universally across all schools and classrooms (Design and Technology Association, 2023). This tendency towards a restricted focus impacts the subject in many ways, such as its reputation for being a less rigorous subject (Blom, 2022), its uptake for further study at Key Stage 4 (Spendlove, 2023b) (see Figure 1), and the amount of time and resources allocated to the subject; all contributors to the further decline of the subject (Banks & Williams, 2023; Spendlove, 2023b).

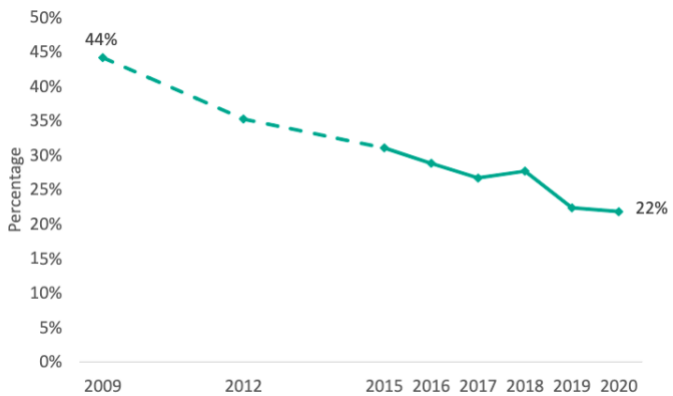

Figure 1 - Percentage of students at the end of key stage 4 entered for at least one Design and Technology GCSE (Tuckett, 2022)

Design Thinking

It is well-established that the design process is non-linear and is in fact a cyclical process (von Mengersen, 2023), however it is argued that teachers often pose learning as predominantly making (McLellan & Nicholl, 2013; Mulberg, 1992; Nicholl & Spendlove, 2016), or treat problem-solving as a series of steps, which does not necessarily affect the students' thinking (McCormick, 2004), therefore they remain in the procedural knowledge space, impeding the development of authentic problem-solving skills (Nicholl et al., 2013; Nicholl & Spendlove, 2016; Demetriou & Nicholl, 2022). As a result of a lack of time and students' understanding of contexts, the design process can be impeded, leading to poorer outcomes (Demetriou & Nicholl, 2022), highlighting the impact of authentic D&T activities. This provides an opportunity to investigate ways in which students engage in design-based research activities which centre around problem-solving.

Design thinking is a concept that gained significant traction over the past decade yet was first introduced as a concept as early as 1987 (Kimbell, 2011), although the term is used to describe two groups of activities, which adds confusion. Design thinking (verb) is thinking as a designer or engaging in professional design activities known as designerly thinking, which was popularised by the work of Nigel Cross (2011). Design Thinking (noun) represents a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test (Interaction Design Foundation, 2023). Design thinking as a methodology has seen the most growth in recent years within the business and management space (Cross, 2023; Razzouk & Shute, 2012), but has also seen significant growth within the design field (Dorst, 2011), and in education (Koh et al., 2015; T. Li & Zhan, 2022; Lor, 2017; Pande & Bharathi, 2020; Park et al., 2023). To ensure clarity, design thinking as a problem-based learning model (Park et al., 2023) was referred to as Design Thinking Integrated Learning (DTIL) by T. Li & Zhan (2022), a term which has also been adopted in this study to avoid confusion with D&T.

The design thinking cycle is particularly suited to dealing with ill-defined and wicked problems as described by Buchanan (1992, as cited in Cross, 2023). The exposure to these sorts of complex, real-world problems is of interest in education because it helps to prepare students to deal with uncertainty and ambiguity (Koh et al., 2015). DTIL is gaining recognition in education (Henriksen et al., 2020), due to its focus on complex problem solving. It is posited that DTIL supports the creation of new knowledge and ideas, but it also contributes to the development of skills in making and doing, as well as dealing with ambiguity, in addition to working and empathising with others (Carroll et al., 2010; Goldman & Zielezinski, 2022; Koh et al., 2015), all valuable skills and competencies required for success in today's world. The facilitation of DTIL contributes to the holistic development of children and is particularly relevant to education in schools, therefore this methodology, especially in its relation to 21st-Century Skill development, is of interest. The implementation of DTIL in K-12 education has indicated an upward trend, as evidenced by recent systematic literature reviews (Li & Zhan, 2022; Rusmann & Ejsing-Duun, 2022), with a notable surge in publications post-2017. However, the application of DTIL as a design-based methodology within educational curricula can be complex, given global variations in design education, the emphasis on STEM, and an emphasis on interdisciplinary learning. Despite these challenges, DTIL is increasingly viewed as a crucial means to develop 21st-Century competencies.

Current research on the implementation of DTIL in schools is still developing, along with the necessary tools and strategies for its effective integration (Gardner, 2008; Koh et al., 2015; Öztürk & Korkut, 2023; Rusmann & Ejsing-Duun, 2022; Yeung & Ng, 2023). Therefore, this study seeks to contribute to this emerging area of research, particularly within the primary and secondary education contexts where there is a gap in the literature (Li & Zhan, 2022), and aims to demonstrate how DTIL can be effectively utilised to enhance the learning experience and skill development of these younger students.

There are more than twelve design thinking models available (Liu et al., 2024), which educators use to facilitate students' engagement with the design thinking process and to enhance their understanding of its core principles (T. Li & Zhan, 2022). Typical models, such as the IDEO process model (Discovery, Interpretation, Ideation, Experimentation, and Evolution) (IDEO, 2012), the Stanford d.school's five iterative stages (Empathize, Define, Ideate, Prototype, Test) (Hasso Plattner Institute of Design at Stanford University, 2018) and the Double Diamond model (Discover, Define, Develop and Deliver) (Design Council, 2005), have been adopted in primary and secondary education (Li & Zhan, 2022). The five stage process developed by the Stanford d.school was utilised in this study, due to its prevalence in the literature concerning design thinking integration within education.

Design thinking fundamentally employs a unique form of reasoning known as 'abductive' reasoning, distinct from traditional deductive and inductive logic (Kolko, 2010). Deductive reasoning operates from a general-to-specific framework, determining what necessarily must be true, while inductive reasoning moves from specific observations to broader generalisations, focusing on what actually is (Rao et al., 2022). Abductive reasoning, in contrast, concerns exploring possibilities as opposed to asserting truth, which forms the centre of DTIL, and within the realm of design more generally (Lawson, 1997). Reasoning within DTIL does not aim to declare a conclusion as definitively true or false but instead seeks to uncover a range of potential outcomes or scenarios. This mode of thinking is essential in DTIL (Rao et al., 2022) as it allows for the consideration of various possibilities and innovative solutions that may not be immediately apparent through conventional logical approaches, thus making DTIL a valuable pedagogical model, particularly for equipping students with skills that would enable them to cope with 21st-Century demands (Retna, 2016), and potentially serving as a "model of thinking" for the contemporary student (Y. Li et al., 2019, p. 94).

D&T education offers a unique combination of disciplinary knowledge and practical application, fostering an environment where students can engage in hands-on learning and creative problem-solving (von Mengersen, 2023). This approach enhances their understanding of design principles and providing them with the necessary skills to drive innovation and adaptability (Blom, 2022). D&T embraces an interdisciplinary approach, integrating aspects of predominately design, and technology, but also science, arts, and humanities (McLain et al., 2019). This broadens students' perspectives, allowing them to apply their skills in various contexts and encouraging them to challenge conventional paradigms (McLain, 2023). In essence, D&T education is focused on cultivating an innovative approach, creativity, and adaptability, through the signature pedagogies of designing, making, and critiquing (McLain, 2020, 2022, 2023). These are the diverse set of skills that will enable students to thrive in the 21st-Century (Razzouk & Shute, 2012), thus establishing design education as a crucial element of

early general education to produce rounded and successful members of society (Barlex & Steeg, 2017; Beaumont & Steeg, 2024).

Methodology

Participants

While n=160 students were exposed to this curriculum intervention, a sample of four participant groups were randomly chosen for this study and ethical approval granted by Liverpool John Moores University. A total of n=16 participants worked in teams of four with each group belonging to a different class. All participants are aged 12-13 years (Year 8). Year 8 was selected as the curriculum year group for this intervention because students are mid-way through their Key Stage 3 D&T study. Year 7 students at the focus school arrive from over fifty different primary schools, therefore students begin secondary education with varying experiences of D&T at primary level, and with this, varying levels of expertise and knowledge. By the end of Year 7, there is some parity in the knowledge and skills of the students due to the curriculum they experience, therefore Year 8 presents as a more appropriate stage to conduct such an intervention. A constructivist intervention such as DTIL requires a foundation knowledge on which to build upon, and as Ausubel (1968) posits, the most important factor that influences learning is what the learner already knows; new knowledge is therefore interpreted and then connected to existing knowledge (Dennick, 2016). Without this foundation knowledge, students would be unable to deepen their understanding of established concepts, thus reducing the quality of learning outcomes during the intervention. This foundation is afforded in Year 7 D&T, providing the conditions required in Year 8 to successfully build on this, while offering more freedom in the process.

Intervention Structure

The intervention spanned twelve 55-minute weekly lessons, including homework tasks between sessions. Although delivered to ten classes through forty different contexts, the structure remained consistent.

Observe and Empathise Phases (Sessions 1-2)

Session 1: Students watched a video on design thinking (Belfast Met, 2022), learned about effective interviewing, empathising, and communication techniques, and viewed a video of a chef's experience to build empathy. They created problem statements starting with "how might we…" (Lewrick et al., 2020).

Session 2: Students visited end-users, documented observations, and developed problem statements as design briefs. They reflected on their feelings, observations, and problem-solving strategies in their journals.

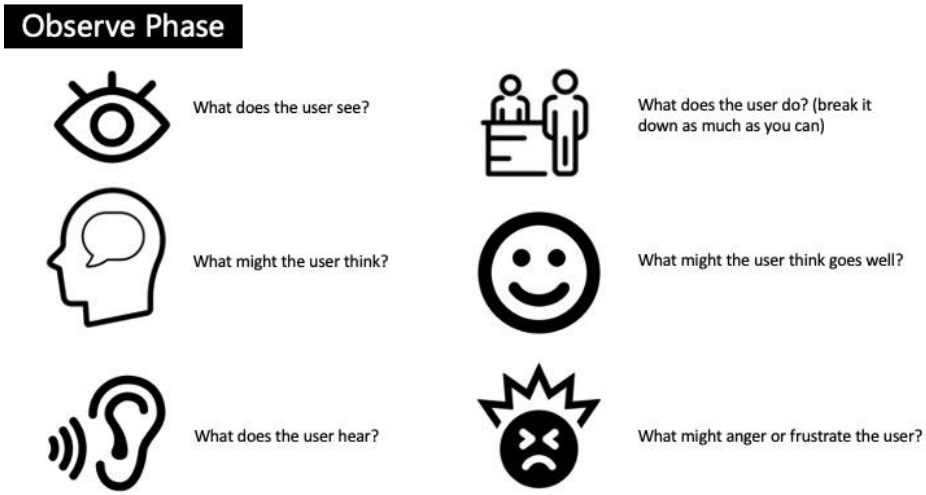

Figure 2 - Observe Phase Activity

Ideation Phase (Session 3)

Students converted circles into objects based on an activity by T. Kelley & Kelley (2013), discussed creativity, and generated 40 ideas in 15 minutes using coloured post-it notes. Ideas were reviewed using an adapted dot-voting activity (Goldman & Zielezinski, 2022). Reflective journals focused on the ease of idea generation and user feedback.

Figure 3 – Example of a range of ideas generated during this session.

Prototyping Phase (Sessions 4-10)

Session 4: Students shared ideas with end-users, developed concepts using card modelling and 3D CAD (Shapr3D), and gathered feedback.

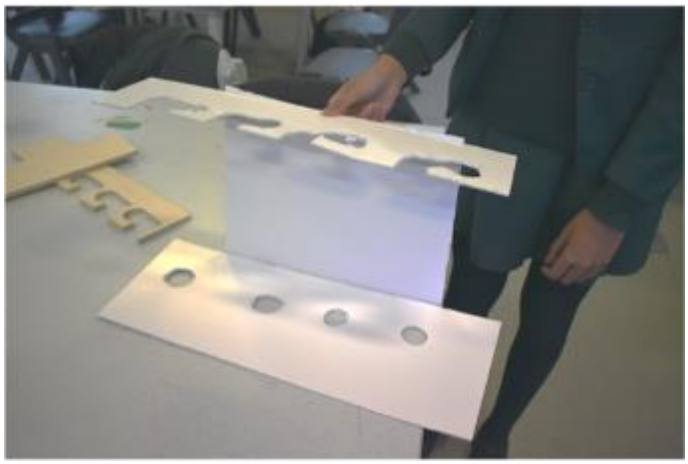

Figure 4 - Example of a foam board model produced during this session.

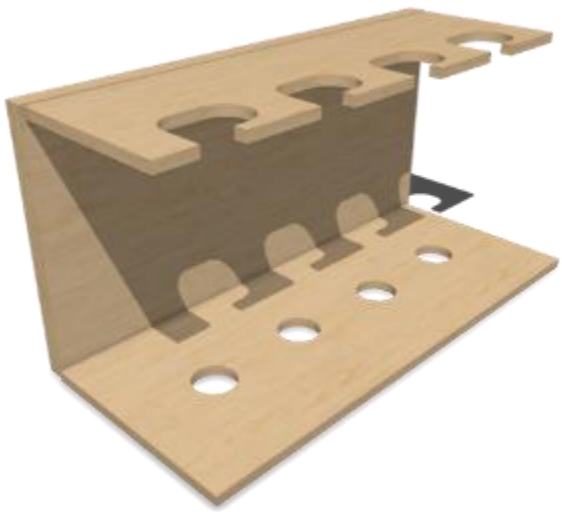

Figure 5 - Example of a 3D CAD model produced during this session.

Session 5: Technical considerations were addressed, including materials, components, and manufacturing processes.

Sessions 6-10: Students focused on product manufacturing, reflecting on tools used, accuracy, teamwork, and learning needs.

Consolidation Task (Session 10)

Students considered how their D&T knowledge had developed by using the 'Big Ideas for D&T' as a framework (Barlex & Steeg, 2017; Beaumont & Steeg, 2024) as part of presentation planning.

Testing Phase (Session 11-12)

Students presented products to end-users, conducted tests, and began planning their final presentations. Reflective journals assessed product success, construction quality, and team effectiveness. Students presented their design process orally to their class.

Methods

There is an increasing necessity to assess 21st-Century Skills (Voogt & Roblin, 2012) using a variety of tools instead of traditional tests (Geisinger, 2016; Miliou et al., 2023), with a movement towards adopting assessment strategies centred around self-assessment and reflection (Care & Kim, 2018; Miliou et al., 2023) as a more comprehensive way of assessing 21st-Century Skills. There are calls for a wider variety of assessment instruments (Greenstein, 2012; P21, 2007), for example, performance-based assessments, rubrics, portfolios, and peer and self-assessment, to provide a more comprehensive perspective on 21st-Century Skill development (Foster & Piacentini, 2023).

Performance-Based Assessments (PBA) involve tasks that require students to apply their skills in real-world or simulated scenarios, making them suitable for evaluating 21st-Century Skills (Stanley, 2021). PBA appraises students on items such as portfolios, projects, and writing samples, and provides teachers with the opportunity to give more nuanced feedback compared to traditional testing (ibid.). Rubrics are often used to assess performance; clear criteria for 21st-Century Skills can offer detailed descriptors for different skill levels, focusing on both the process and product of learning activities (Barnes et al., 2022), with well-written rubrics clarifying for students the expectations of the assessment and acting as a framework for students to use, and also increasing student motivation (Zhao et al., 2021). Rubrics can enhance consistency in assessment between teachers (Stanley, 2021), however, while rubrics are effectively used for assessing knowledge, they can be more difficult to use in the measurement of growth in relation to 21st-Century Skills (Kelley et al., 2019), although remain a useful way of assessing skills when students engage with DTIL specifically (Goldman & Zielezinski, 2022; Taheri et al., 2016).

Digital portfolios are another popular assessment method for 21st-Century Skills. They allow students to showcase their work and reflections over time, offering insights into their skill development (Shively et al., 2018). Portfolios can include various works, providing a comprehensive view of students' application of 21st-Century Skills (Greenstein, 2012). This intervention requires students to keep an online portfolio for reflections, which is also used to support their summary presentation at the end of the project.

Peer and self-assessments capture interpersonal and intrapersonal skills like collaboration, communication, and self-regulation, promoting reflective learning (Andrade & Valtcheva, 2009). An example of a self-reporting tool to assess the 4Cs in high school students is the ‘21st Century Instrument’ (Kelley et al., 2019), which provides a framework for students to evaluate their own proficiency in these areas, reflecting on their perceptions of their skills in critical thinking, creativity, collaboration, and communication. A student survey is a useful instrument for educational researchers and educators seeking to monitor and promote the students’ abilities in 21st-Century Skills, however there are very few self-reporting instruments for measuring 21st-Century Skills holistically (ibid.), as most typically focus on a particular aspect, such as creativity (Demetriou & Nicholl, 2022; OECD, 2019a).

There is advocacy by the OECD for designing long-term units of learning whereby students are allowed to be creative (Foster & Piacentini, 2023). The design of products is an example given, which provides "low floors, high ceilings" (ibid., p. 29), allowing the weakest and strongest of students to succeed and develop their 21st-Century Skills. A longer unit of work provides more opportunities to assess skills using a variety of methods, which is especially useful when situated in a domain specific context where disciplinary knowledge may be assessed more traditionally, alongside the other assessment instruments.

To assess the development of 21st-Century Skills alongside subject-specific knowledge, a mixed methods approach was adopted. The selected methods included the '21st Century Instrument' developed by T. R. Kelley et al. (2019), administered both before and after the intervention, as well as student work, reflections, and presentation audio recordings. Mean point scores were used to analyse the intervention's impact on participants' self-reflections. Additionally, a rubric inspired by the Big Ideas for D&T (Barlex & Steeg, 2017; Beaumont & Steeg, 2024), shown in Table 1, was developed as a framework for mapping areas of knowledge and assessing mastery. It should be noted that this rubric's scope covers the entirety of Key Stage 3 (and beyond), and this curriculum intervention alone would not adequately cover all criteria in depth.

There is clear overlap in some of the D&T knowledge-based criteria and 21st-Century Skills, such as 'critical thinking and innovation' and 'reflection and adaptability,' which are considered D&T knowledge rather than skills in this context. A second rubric, the '21st Century Learning Design Student Work Rubric' developed by SRI International (2012) in collaboration with Microsoft, was adapted to assess the extent to which participant teams developed their 21st-Century Skills across four of its six areas: collaboration, knowledge construction (critical thinking), real-world problem-solving and innovation (creativity), and skilled communication. These rubrics were shared with students before the intervention to support and frame their learning.

Table 1 – Rubric used to assess learning during intervention.

Conceptual Understanding and Application	
Developing	Basic grasp of material properties, maths, and science integration, and an introductory understanding of historical impacts and market opportunities.
Secure	Solid application of concepts to design projects with an understanding of historical contexts and ability to identify market opportunities.
Excellent	Demonstrates advanced integration of interdisciplinary knowledge, utilising a deep understanding of materials, scientific principles, historical insights, and market trends to develop innovative designs.
Critical Thinking and Innovation	
Developing	Begins to apply creative thinking and problem-solving in design projects, exploring multiple solutions with some understanding of their potential impact.
Secure	Employs critical analysis and creativity to develop innovative and effective design solutions, considering a broad range of possibilities and implications.
Excellent	Exhibits exceptional innovation in design, pushing boundaries with original solutions and sophisticated problem-solving that anticipates future trends and challenges.
Ethical Consideration and Social Impact	

Developing	Recognises the importance of designing for inclusivity, sustainability, and social justice, with initial steps towards ethical considerations in design decisions.
Secure	Integrates ethical considerations deeply into the design process, aiming for solutions that address social justice, environmental stewardship, and inclusivity.
Excellent	Generates designs that consider deeply ethical practices, sustainability, and social impact, demonstrating a commitment to advancing societal and environmental well-being.
Reflection and Adaptability	
Developing	Shows basic reflection on design choices and some responsiveness to feedback and unintended consequences.
Secure	Actively seeks feedback, demonstrates adaptability in design revisions, and considers a wide range of impacts and feedback loops in the iterative design process.
Excellent	Exemplifies a reflective and adaptive design approach, using feedback and critical evaluation to refine and evolve designs continually. Demonstrates foresight in anticipating consequences and integrates learning into future innovation.

Findings

Examinations Officer

Students met with the school's Examinations Officer to explore the challenges she encounters in her role. A significant aspect of her duties includes the transportation of exam papers from a secure storage area in her office to the examination hall, located on the opposite side of the school. The students discovered that the Examinations Officer relied on a commercially purchased plastic trolley for this task. However, they noted that the trolley was difficult to manoeuvre, lacked stability and security when unfolded, and caused the exam papers to become jumbled and difficult to access, given the number of different qualifications being examined during the same session.

Individually and then collectively, students formulated the following problem statement to guide their investigations and design work, as well as to establish criteria for evaluating success: "How might we develop a way to transport exam papers easily and securely, while dividing them according to the specific exam?"

Figure 6 – Photograph of the practical outcome from the 'exams' team.

The validated self-assessed instrument used before and after the intervention (Kelley et al., 2019) contained n=30 questions that were grouped to each of the 4C's. Students were asked to what degree they agreed with each statement using a four-point Likert scale. Four-point as opposed to five was chosen to force choice (Chyung et al., 2017) and avoid respondents remaining in the mid-points of the scale. Figure 4 shows the mean scores, alongside a teacher assessed score based on the rubric to assess student work for 21st-Century Skills (SRI International, 2012).

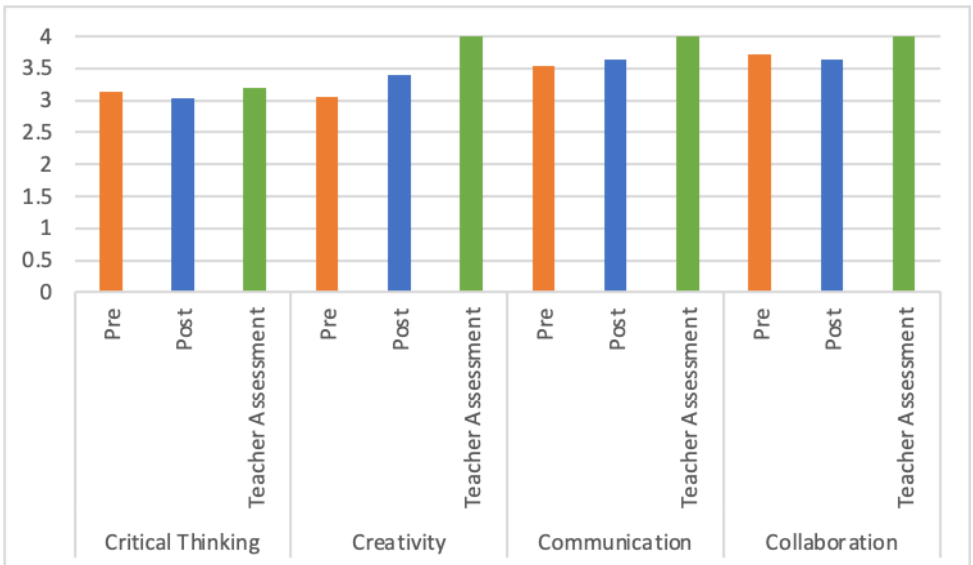

Figure 7 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Cooking and Nutrition Teacher

Students engaged with one of the school's cooking and nutrition teachers and students participating in cooking classes to identify challenges encountered in this context. They learned that laundry management posed difficulties both for the teacher and the students. Used kitchen linens were collected in a laundry basket, cleaned daily by the school's Housekeeper, and returned in a large bag. The teacher was responsible for storing these items in a cupboard, which became a point of congestion during lessons as students needed access to clean tea towels and oven mitts.

Students individually and then collectively formulated the following problem statement to guide their investigations, design work, and to establish criteria for evaluating success:

> *"How might we keep the laundry organised for the students so that cooking is safer and easier? We are restrained by space and the students misusing our product."*

Figure 8 - Photograph of the practical outcome from the 'laundry' team.

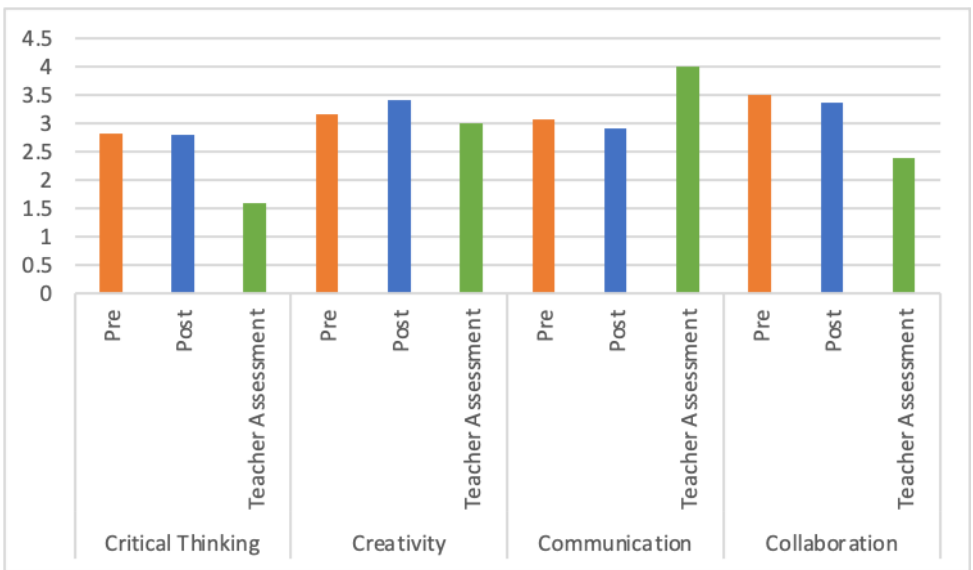

Figure 9 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Housekeeper

Students consulted with the school's housekeeper to identify challenges she encountered in her role. As the manager of the cleaning staff, she is responsible for ensuring the school's cleanliness meets high standards and adheres to Health and Safety regulations. The students discovered an issue with the storage of used mops; they were kept upside down in a large bin, causing the mop heads to touch. The housekeeper highlighted that this storage method was unsuitable due to the risk of cross-contamination and required a better storage solution.

Students individually and then collectively formulated the following problem statement:

> *"How might we make sure that the mops are kept tidy and out of the way so that people won't get hurt by them, as well as ensuring they are separated? We are restrained by space and the size of the mops."*

Figure 10 - Photograph of the practical outcome from the 'laundry' team.

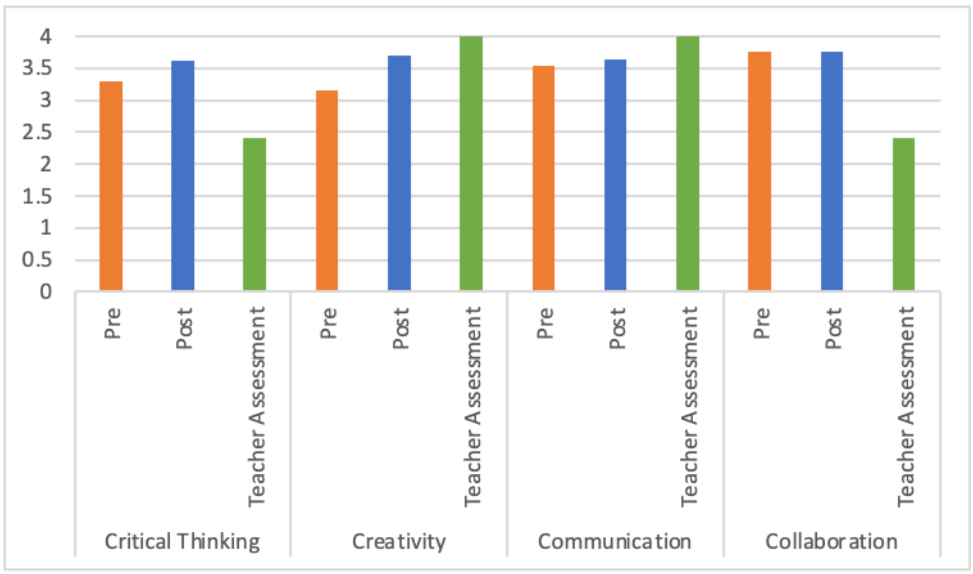

Figure 11 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score.

Music Teacher

Students engaged with one of the school's music teachers to identify challenges within the Music Department. Through their inquiry, they learned that the weekly transport of hymn sheets and Order of Mass cards to the local church posed significant difficulties. The task involved students manually carrying bulky and heavy boxes across a busy road, presenting concerns related to both health and safety and practicality.

Students individually and then collectively formulated the following problem statement:

> *"How might we develop a way to transport hymn sheets and Order of Mass cards between the school and St. Joseph's church in a more efficient and safe manner? We are restrained by the number of cards and their size."*

Figure 12 - Photograph of the practical outcome from the 'mass cards' team.

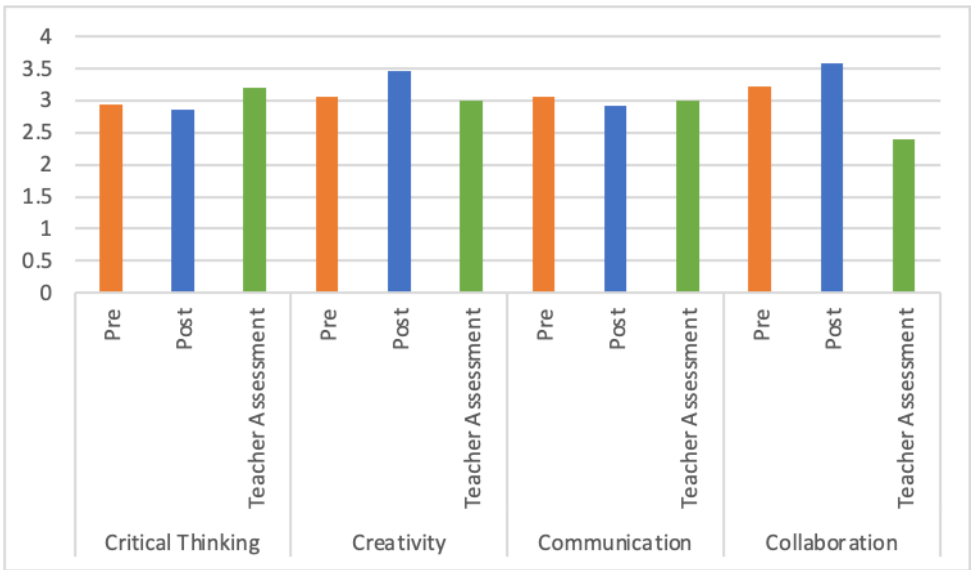

Figure 13 – Mean scores of student perceptions of their 4C skills before and after the intervention, along with the teacher assessment score

Discussion

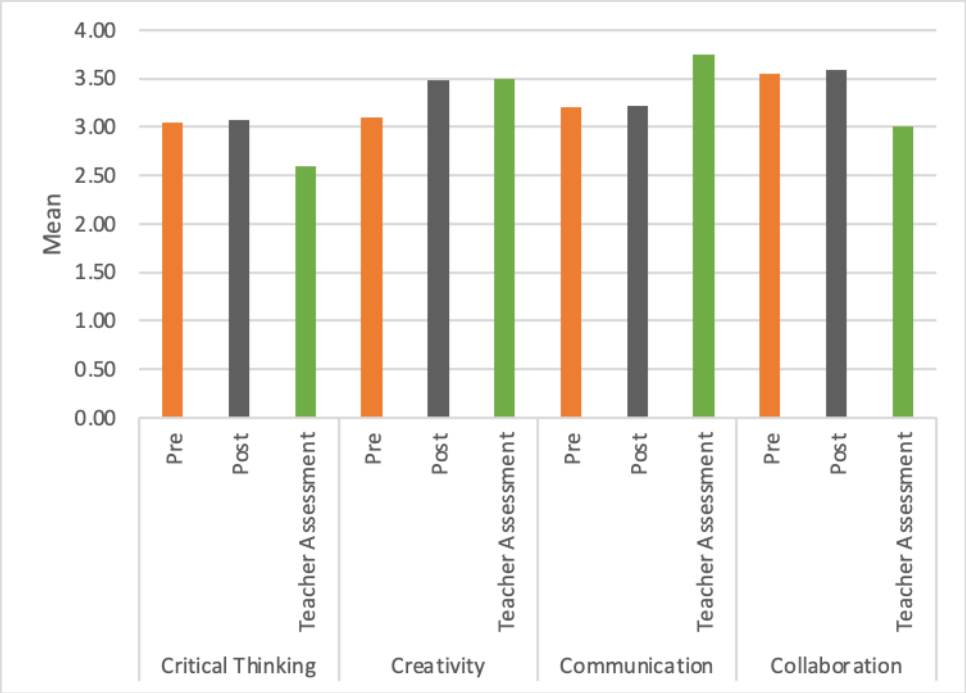

Figure 14 - Mean scores of student perceptions of their 4C skills before and after the intervention for all participants, as well as teacher assessment using rubric.

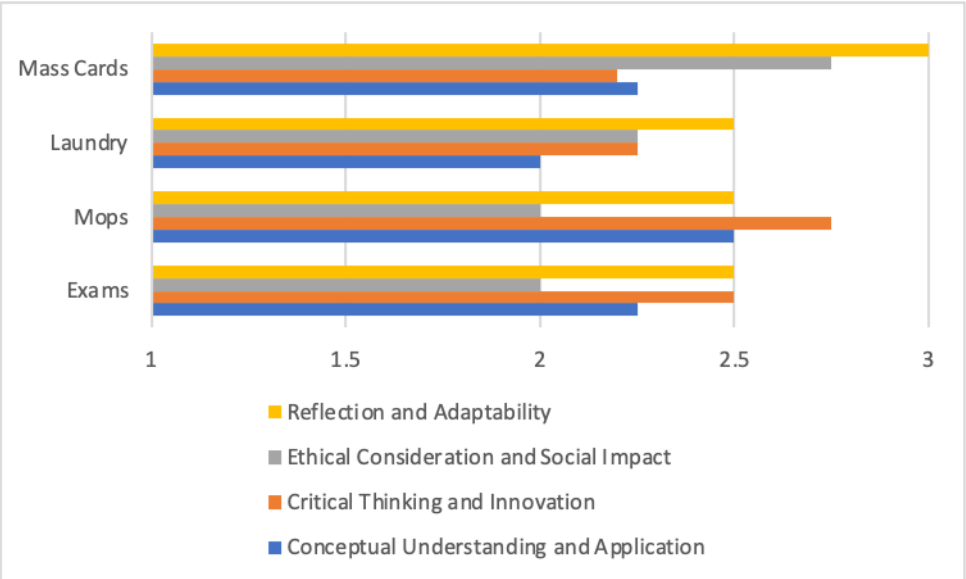

Figure 15 – Mean scores of teacher assessments of D&T knowledge, ranging from 1 (developing) to 3 (excellent) as detailed in Table 1.

Figure 15 illustrates an increase in mean scores across all 4Cs following the intervention, as measured by the self-assessment instrument. However, these increases are generally marginal, with the notable exception of creativity, which shows a more significant improvement. This finding is further supported by the teacher's assessment of creativity.

It is widely acknowledged that when individuals face a problem, they often automatically apply strategies that have proven effective in similar or analogous situations they have previously encountered (Thornhill-Miller et al., 2023). The innovative nature of this curriculum approach introduced students to many novel situations, prompting them to develop new approaches and experiences. This process significantly enhanced their skills across the 4Cs, with a particular emphasis on creativity.

Contrary to traditional views, it is argued that creativity is not an innate trait but a skill that can be cultivated (Nicholl and Spendlove, 2016; Thornhill-Miller et al., 2023), which is supported by the data from this study. It is believed that creativity can be actively taught through direct instruction in creative methods and concepts, as well as indirectly fostered by creating environments conducive to creativity (Chiu, 2015; Thornhill-Miller and Dupont, 2016). Creativity, sharing certain underlying mechanisms with intelligence (Spendlove, 2011), is increasingly acknowledged as a vital skill for adaptability and problem-solving in complex situations (Sternberg, 1986; Craft, 2005), therefore highlighting its importance in a 21st-Century context.

Creativity has become recognised as a crucial skill in the global educational landscape. It operates outside of traditional academic boundaries, playing a critical role in students' ability to innovate, adapt, and solve complex problems in a rapidly changing world (Robinson, 2006; Weisberg, 2006). Creativity in the 21st-Century context transcends artistic expression, enabling the ability to think critically and innovatively, and apply knowledge in new ways (Shaheen, 2010), emphasising the crossover of the 4Cs. It is increasingly recognised as a key component of education, vital for success in diverse fields ranging from technology to business (Craft, 2005). Creative thinking can be viewed as a tangible competence, grounded in knowledge and practice while offering flexibility and adaptability, which supports individuals in achieving better outcomes, often in constrained and challenging environments (Sternberg, 1986; OECD, 2019a), which further highlights its importance for the future. Organisations and societies around the world increasingly depend on innovation and knowledge creation to address emerging challenges (OECD, 2010), placing emphasis on innovation and creative thinking collectively.

Educators face the challenge of creating learning environments that encourage risk-taking and original thinking while still ensuring mastery of essential content (Robinson, 2006). There is increasing evidence that educational practices are incorporating project-based learning, inquiry-based learning, and collaborative tasks that foster creative thinking and problem-solving skills (Bell, 2010), alongside the development of subject knowledge, which encourages students to explore, experiment, and engage with content in innovative ways, which are crucial for developing creativity (Craft, 2005; Klapwijk, 2017). While creativity necessitates freedom and flexibility, it also thrives on deep subject knowledge (Weisberg, 2006), demanding a balance. This is more challenging in areas where traditional curricula focus heavily on rote learning and standardised testing (Zhao, 2012), which is the current trend in England with its knowledge-centric curriculum (Bell et al., 2017; McLain et al., 2019). Though small-scale, this study highlights that there was success in integrating a constructivist approach to problem-solving, which enhanced 21st-Century Skills alongside subject specific knowledge. The study established that in order to be creative with design and practical work, capability was predicated on prior knowledge and experience. In the time constraints of this project, the student outcomes they produced would not have been possible by introducing concepts for the

first time; therefore, students were required to draw on prior knowledge and build on this socially, with assistance from their peers and teachers, a key component of constructivism, particularly constructionism (Papert, 1980).

Communication inherently connects with the other 3Cs. In relation to critical thinking, effective communication fosters an environment conducive to goal-oriented, realistic exchanges (Griffin & Care, 2015; Trilling & Fadel, 2009). It is closely linked to collaboration, as successful teamwork relies heavily on quality knowledge sharing and the trust that develops among group members (Johnson & Johnson, 2009). Furthermore, creativity in communication is particularly evident when ideas are conveyed to an audience or during collaborative creative endeavours. The data from this investigation suggests that students tended to rate their communication skills lower than that of the teacher, possibly indicating that the self-assessment of communication did not correlate with the teacher assessment rubric or that students did not have confidence in their communication abilities. Communication during this curriculum project was essential in all activities, including face-to-face collaboration, working with end-users, presenting to peers, and visually through sketching, modelling, and writing, as well as during practical activities. This intervention provided a wide range of opportunities for communication skills, and associated knowledge to be developed.

Limitations of the Study

This study is limited in scale, which precludes the generalisation of its findings. Additionally, a further limitation is the use of broad instruments; a more focused examination of knowledge and skill acquisition in specific areas could yield a more nuanced understanding of how DTIL can support learning, rather than the broader approach taken in this study. Employing a more analytical method, such as content analysis of student work, could lead to a better understanding of how different contexts impact learning, especially on an individual student level, given that some analyses in this study focused on group assessments.

Employing the knowledge rubric as a standard assessment tool across the Key Stage could have supported pre- and post-intervention analysis to more accurately assess its impact. Adopting a more comprehensive approach to analysing data from the self-assessment instrument, such as using standard deviations and paired sample t-tests, could have identified whether the gains were statistically significant, thereby providing a clearer understanding of skill development and the effectiveness of the curriculum design.

Additionally, the effectiveness of the curriculum design itself was not evaluated in this study; further exploration in this area would be beneficial. Similar to the '21st Century Learning Design Student Work Rubric' developed by SRI International (2012), the organisation also published the ‘21CLD Learning Activity Rubrics’ (SRI International, 2012), a framework for assessing the effectiveness of learning activities, which could have contributed to the development of a more effective curriculum design. Incorporating additional methods, such as focus groups or interviews, could provide a richer dataset to analyse the impact of this intervention.

Implications of the Study

While this small-scale study highlights a range of fruitful outcomes and makes some progress in establishing that this curriculum intervention supports the development of 21st-Century Skills alongside knowledge, there is an opportunity to further capitalise on developing core subject

knowledge, such as the inclusion of electronic or mechanical systems. In future iterations of this intervention, students could be required to consider key aspects of the curriculum to satisfy knowledge progression, in addition to human skills. A disadvantage of prioritising specific subject content to ensure adequate delivery is that the authentic problem-solving element of this project could be compromised, making design activities contrived.

The inclusion of users from outside of the school, for instance in the community or in industry could enhance this intervention and potentially improve the development of 21st-Century Skills. The careful selection of contexts to enable sufficient coverage of subject content would be imperative. An example of an upcoming project with Year 8 students which is more constrained involves input from an audiologist at a local hospital. There have been strict cleanliness rules established since the COVID-19 pandemic, consequently a child-centred product used during paediatric hearing tests can no longer be used, requiring a new solution made entirely of polymers. This project has the potential to include many areas of D&T subject content, including systems, but will require teachers to teach more specifically about polymers and manufacturing from this material. On the one hand, students are more likely to develop a deeper knowledge of polymers due to the context, yet this could potentially limit the development of knowledge of a wider variety of materials.

Conclusion

This study conducted at Key Stage 3 in D&T offers insight into DTIL and its impact on fostering 21st-Century Skills alongside subject-specific knowledge. The DTIL approach, implemented through a structured intervention, has demonstrated its effectiveness in engaging students in real-world problem-solving tasks that enhance their creativity, collaboration, communication, and critical thinking skills. By departing from traditional pedagogies within D&T and embracing Design Thinking, the findings highlight the potential of an innovative curriculum framework in preparing students for the complexities of modern life and work.

The study also identifies significant challenges, primarily the existing educational emphasis on knowledge acquisition over skill development within the English curriculum. This emphasis potentially undermines the creative and practical dimensions of learning that are crucial for students to thrive in a 21st-Century context. The research illustrates a need for educational policies and curricula that balance subject knowledge with human skills, ensuring that education is comprehensive and relevant, emphasising the role that D&T can play in general education.

In conclusion, this study contributes to the ongoing discourse on reform in D&T by providing some evidence of the benefits of integrating 21st-Century Skills and Design Thinking into the curriculum. Moving forward, it will be necessary to expand this research to larger and more diverse populations to further validate and refine the DTIL model, along with the refinement of instruments to measure its impact.

References

Ananiadou, K., & Claro, M. (2009). *21st Century Skills and Competences for New Millennium Learners in OECD Countries*. https://doi.org/10.1787/19939019

Andrade, H., & Valtcheva, A. (2009). Promoting Learning and Achievement Through Self-Assessment. *Theory Into Practice*, *48*(1), 12–19. https://doi.org/10.1080/00405840802577544

Ausubel, D. Paul. (1968). *Psychology: A Cognitive View*. New York. Holt, Reinhart and Winston Inc. https://archive.org/details/in.ernet.dli.2015.112045/mode/2up

Banks, F., & Williams, P. J. (2023). International perspectives on technology education. In A. Hardy (Ed.), *Debates in Design and Technology Education* (pp. 26–44). Routledge. https://doi.org/10.4324/9781003166689-4

Barlex, D., & Steeg, T. (2017). *Re-Building Design & Technology In the secondary school curriculum*. https://dandtfordandt.files.wordpress.com/2017/05/re-building-dt-v21.pdf

Barnes, M., Lafferty, K., & Li, B. (2022). Assessing twenty-first century competencies: can students lead and facilitate the co-construction process? *Educational Review*, 1–19. https://doi.org/10.1080/00131911.2022.2142524

Battelle for Kids. (2019). *Framework for 21st Century Learning*. https://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf

Beaumont, H., & Steeg, T. (2024). *Design and Technology in your School*. Routledge. https://doi.org/10.4324/9781003008026

Belfast Met. (2022). *What is Design Thinking?* YouTube. Retrieved February 22, 2024, from https://www.youtube.com/watch?v=1khRrQfyZ0M

Bell, D., Wooff, D., McLain, M., & Morrison-Love, D. (2017). Analysing design and technology as an educational construct: an investigation into its curriculum position and pedagogical identity. *The Curriculum Journal*, *28*(4), 539–558. https://doi.org/10.1080/09585176.2017.1286995

Biesta, G. (2014). Pragmatising the curriculum: bringing knowledge back into the curriculum conversation, but via pragmatism. *The Curriculum Journal*, *25*(1), 29–49. https://doi.org/10.1080/09585176.2013.874954

Blom, N. (2022). Design cognition in design and technology classrooms. In *Debates in Design and Technology Education* (pp. 209–220). Routledge. https://doi.org/10.4324/9781003166689-18

Brown, K., & Woods, K. (2022). Thirty years of GCSE: A review of student views and experiences. *Assessment in Education: Principles, Policy & Practice*, *29*(1), 51–76. https://doi.org/10.1080/0969594X.2022.2053946

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, *8*(2), 5. https://doi.org/10.2307/1511637

Care, E., & Kim, H. (2018). Assessment of Twenty-First Century Skills: The Issue of Authenticity. In E. Care & P. W. M. Griffin (Eds.), *Assessment of Twenty-First Century Skills: Educational Assessment in an Information Age* (pp. 21–39). Springer. https://doi.org/10.1007/978-3-319-65368-6_2

Bereiter, C., & Scardamalia, M. (2018). Fixing Humpty Dumpty. In L. Kerslake & R. Wegerif (Eds.), *Theory of Teaching Thinking: International Perspectives* (1st ed.). Routledge. https://doi.org/10.4324/9781315098944-6

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, Imagination and the Fires Within: Design Thinking in a Middle School Classroom.

International Journal of Art & Design Education, *29*(1), 37–53. https://doi.org/10.1111/j.1476-8070.2010.01632.x

Christodoulou, D. (2023, November 13). *Skills vs knowledge, 13 years on*. No More Marking. Retrieved November 15, 2023, from https://substack.nomoremarking.com/p/skills-vs-knowledge-13-years-on

Chyung, S. Y. Y., Roberts, K., Swanson, I., & Hankinson, A. (2017). Evidence-Based Survey Design: The Use of a Midpoint on the Likert Scale. *Performance Improvement*, *56*(10), 15–23. https://doi.org/10.1002/pfi.21727

Cross, N. (2011). *Design Thinking: Understanding How Designers Think and Work* (1st ed.). Berg Publishers.

Cross, N. (2023). Design thinking: What just happened? *Design Studies*, *86*. https://doi.org/10.1016/j.destud.2023.101187

de Vries, M. J. (2005). *Teaching About Technology: an introduction to the philosophy of technology for non-philosophers* (W. W. Cobern, K. Tobin, H. Brown-Acquay, M. Espinet, G. Irzik, O. R. Jegede, L. Reyes Herrera, M. Rollnick, S. Sjøberg, & H. Tuan, Eds.). Springer Dordrecht. https://doi.org/10.1007/1-4020-3410-5

Desforges, C. (1995). Introduction to teaching: psychological perspectives. (1st ed.). John Wiley and Sons Ltd.

Demetriou, H., & Nicholl, B. (2022). Empathy is the mother of invention: Emotion and cognition for creativity in the classroom. *Improving Schools*, *25*(1), 4–21. https://doi.org/10.1177/1365480221989500

Dennick, R. (2016). Constructivism: reflections on twenty five years teaching the constructivist approach in medical education. *International Journal of Medical Education*, *7*, 200–205. https://doi.org/10.5116/ijme.5763.de11

Design and Technology Association. (2023). *Reimagining D&T*. https://www.designtechnology.org.uk/media/4843/reimagining-dt-our-vision-v9.pdf

Design Council. (2005). *The Design Process: What is the Double Diamond?* Retrieved December 8, 2023, from https://www.designcouncil.org.uk/our-resources/framework-for-innovation/

DfE. (2013). *National curriculum in England: design and technology programmes of study*. Retrieved August 8, 2023, from https://www.gov.uk/government/publications/national-curriculum-in-england-design-and-technology-programmes-of-study/national-curriculum-in-england-design-and-technology-programmes-of-study

DfE. (2015a). *Design and Technology GCE AS and A Level Subject Content*. Retrieved August 8, 2023, from www.gov.uk/government/publications/gce-as-and-a-level-design-and-technology

DfE. (2015b). *Design and Technology GCSE Subject Content*. Retrieved August 8, 2023, from www.gov.uk/government/publications/gcse-design-and-technology

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, *32*(6), 521–532. https://doi.org/10.1016/j.destud.2011.07.006

Foster, N., & Piacentini, M. (2023). *Innovating Assessments to Measure and Support Complex Skills*. https://issuu.com/oecd.publishing/docs/innovating_assessments_to_measure_and_support_comp

Gardner, H. (2008). Five minds for the future. *Schools: Studies in Education*, *5*(1/2), 17–24. https://doi.org/10.1086/591814

Geisinger, K. F. (2016). 21st Century Skills: What Are They and How Do We Assess Them? *Applied Measurement in Education*, *29*(4). https://doi.org/10.1080/08957347.2016.1209207

Goldman, S., & Zielezinski, M. B. (2022). Design Thinking for Every Classroom: A Practical Guide for Educators. (1st ed.). Routledge.

Greenstein, L. (2012). Assessing 21st Century Skills: A Guide to Evaluating Mastery and Authentic Learning. (1st ed). Corwin.

Griffin, P., & Care, E. (2015). *Assessment and Teaching of 21st Century Skills*. Springer Netherlands. https://doi.org/10.1007/978-94-017-9395-7

Hasso Plattner Institute of Design at Stanford University. (2018). *Design Thinking Bootleg*. https://static1.squarespace.com/static/57c6b79629687fde090a0fdd/t/5b19b2f2aa4a99e99b26b6bb/1528410876119/dschool_bootleg_deck_2018_final_sm+%282%29.pdf

Henriksen, D., Gretter, S., & Richardson, C. (2020). Design thinking and the practicing teacher: addressing problems of practice in teacher education. *Teaching Education*, *31*(2). https://doi.org/10.1080/10476210.2018.1531841

Hickman, L. A., Neubert, S., & Reich, K. (2009). *John Dewey Between Pragmatism and Constructivism* (L. A. Hickman, S. Neubert, & K. Reich, Eds.). Fordham University Press. https://doi.org/10.1515/9780823237807

IDEO. (2012). *Design Thinking Toolkit for Educators*. https://f.hubspotusercontent30.net/hubfs/6474038/Design%20for%20Learning/IDEO_DTEdu_v2_toolkit+workbook.pdf

Interaction Design Foundation. (2023). *What is design thinking?* Retrieved November 9, 2023, from https://www.interaction-design.org/literature/topics/design-thinking

Johnson, D. W., & Johnson, R. T. (2009). An Educational Psychology Success Story: Social Interdependence Theory and Cooperative Learning. *Educational Researcher*, *38*(5), 365–379. https://doi.org/10.3102/0013189X09339057

Jones, P. A. (2023). Preliminary study of how 21st-Century Skills are developed during a participatory user-centred curriculum intervention at Key Stage 3 in Design and Technology. *The 40th International Pupils' Attitudes Towards Technology Conference Proceedings 2023*. https://openjournals.ljmu.ac.uk/PATT40/article/view/1772

Joynes, C., Rossignoli, S., & Amonoo-Kuofi, E. F. (2019). *21st century skills: Evidence of issues in definition, demand and delivery for development contexts (K4D Helpdesk Report)*. https://assets.publishing.service.gov.uk/media/5d71187ce5274a097c07b985/21st_century.pdf

Kelley, T., & Kelley, D. (2013). *Three Creativity Challenges from IDEO's Leaders*. Retrieved April 24, 2024, from https://hbr.org/2013/11/three-creativity-challenges-from-ideos-leaders

Kelley, T. R., Knowles, J. G., Jung, H., & Euisuk, S. (2019). Creating a 21st Century Skills Survey Instrument for High School Students. *American Journal of Educational Research*, *7*(8), 583–590. https://doi.org/10.12691/education-7-8-7

Kimbell, L. (2011). Rethinking Design Thinking: Part I. *Design and Culture*, *3*(3), 285–306. https://doi.org/10.2752/175470811X13071166525216

Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H.-Y. (2015). *Design Thinking for Education*. Springer Singapore. https://doi.org/10.1007/978-981-287-444-3_1

Kolko, J. (2010). Abductive thinking and sensemaking: The drivers of design synthesis. *Design Issues*, *26*(1). https://doi.org/10.1162/desi.2010.26.1.15

Lamri, J., & Lubart, T. (2023). Reconciling Hard Skills and Soft Skills in a Common Framework: The Generic Skills Component Approach. *Journal of Intelligence*, *11*(6), 107. https://doi.org/10.3390/jintelligence11060107

Lawson, B. (1997). *How designers think*. Architectural Press.

Levy, B. F. (2010). How Technology Changes Demands for Human Skills. *OECD Education Working Paper No. 45*, *33*(45).

Lewrick, M., Link, P., Leifer, L., & Schmidt, A. (2020). *The Design Thinking Toolbox: A Guide to Mastering the Most Popular and Valuable Innovation Methods*. Wiley.

Li, T., & Zhan, Z. (2022). A Systematic Review on Design Thinking Integrated Learning in K-12 Education. *Applied Sciences*, *12*(16), 8077. https://doi.org/10.3390/app12168077

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). Design and Design Thinking in STEM Education. *Journal for STEM Education Research*, *2*(2), 93–104. https://doi.org/10.1007/s41979-019-00020-z

Liu, X., Gu, J., & Xu, J. (2024). The impact of the design thinking model on pre-service teachers' creativity self-efficacy, inventive problem-solving skills, and technology-related motivation. *International Journal of Technology and Design Education*, *34*(1), 167–190. https://doi.org/10.1007/s10798-023-09809-x

Lor, R. R. (2017). Design Thinking in Education: A Critical Review of Literature. *Asian Conference on Education and Psychology*. https://www.researchgate.net/publication/324684320_Design_Thinking_in_Education_A_Critical_Review_of_Literature

MacDonald, G., & Hursh, D. (2006). *Twenty-first Century Schools: Knowledge, Networks and New Economies*. BRILL. https://doi.org/10.1163/9789087901080

McCormick, R. (2004). Issues of Learning and Knowledge in Technology Education. *International Journal of Technology and Design Education*, *14*(1), 21–44. https://doi.org/10.1023/B:ITDE.0000007359.81781.7c

McDiarmid, G. W., & Zhao, Y. (2023). Time to Rethink: Educating for a Technology-Transformed World. *ECNU Review of Education*, *6*(2), 189–214. https://doi.org/10.1177/20965311221076493

McGarr, O., & Lynch, R. (2017). Monopolising the STEM agenda in second-level schools: exploring power relations and subject subcultures. *International Journal of Technology and Design Education*, *27*(1), 51–62. https://doi.org/10.1007/s10798-015-9333-0

McLain, M. (2020). Key pedagogies in design and technology. In A. Hardy (Ed.), *Key pedagogies in design and technology* (4th Edition). Routledge.

McLain, M. (2022). *Secondary Teacher and Teacher Educator Perspectives on 'demonstration' as a Signature Pedagogy for Design and Technology: Implications for Initial Teacher Education* [Doctor of Philosophy by Published Work]. Liverpool John Moores University. https://researchonline.ljmu.ac.uk/id/eprint/18251/

McLain, M. (2023). What's so special about design and technology anyway? In A. Hardy (Ed.), *Debates in Design and Technology Education* (2nd ed., pp. 77–97). Routledge. https://doi.org/10.4324/9781003166689-8

McLain, M., Irving-Bell, D., Wooff, D., & Morrison-Love, D. (2019). How technology makes us human: cultural historical roots for design and technology education. *The Curriculum Journal*, *30*(4), 464–483. https://doi.org/10.1080/09585176.2019.1649163

McLellan, R., & Nicholl, B. (2013). Creativity in crisis in Design & Technology: Are classroom climates conducive for creativity in English secondary schools? *Thinking Skills and Creativity*, *9*, 165–185. https://doi.org/10.1016/j.tsc.2012.11.004

Miliou, O., Adamou, M., Mavri, A., & Ioannou, A. (2023). An exploratory case study of the use of a digital self-assessment tool of 21st-century skills in makerspace contexts. *Educational Technology Research and Development*. https://doi.org/10.1007/s11423-023-10314-0

Morrison-Love, D. (2022). Technological problem solving: an investigation of differences associated with levels of task success. *International Journal of Technology and Design Education*, *32*(3), 1725–1753. https://doi.org/10.1007/s10798-021-09675-5

Mulberg, C. (1992). Beyond the looking glass: technological myths in education. In C. Budgett-Meakin (Ed.), *Make the future work appropriate technology: a teachers' guide*. Longman.

Nicholl, B., Hosking, I. M., Elton, E. M., Lee, Y., Bell, J., & Clarkson, P. J. (2013). Inclusive design in the Key Stage 3 classroom: An investigation of teachers' understanding and implementation of user-centred design principles in design and technology. *International Journal of Technology and Design Education*, *23*(4), 921–938. https://doi.org/10.1007/s10798-012-9221-9

Nicholl, B., & Spendlove, D. (2016). 'Academic Tasks' in Design and Technology Education: Past, Present and Future. In M. J. de Vries, S. Fletcher, S. Kruse, P. Labudde, M. Lang, I. Mammes, C. Max, D. Münk, B. Nicholl, J. Strobel, & M. Winterbottom (Eds.), *Technology Education Today: International Perspectives* (Vol. 1, pp. 125–146). Waxmann Verlag.

Noweski, C., Scheer, A., Büttner, N., Von Thienen, J., Erdmann, J., & Meinel, C. (2012). Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking. In *Design Thinking Research: Measuring Performance in Context*. https://doi.org/10.1007/978-3-642-31991-4_5

OECD. (2019a). *Framework for the Assessment of Creative Thinking in PISA 2021: Third Draft*. Retrieved April 23, 2024, from https://www.oecd.org/pisa/publications/PISA-2021-creative-thinking-framework.pdf

OECD. (2019b). *OECD Future of Education and Skills 2030 Concept Note*. Retrieved August 14, 2023, from https://www.oecd.org/education/2030-project/teaching-and-learning/learning/skills/Skills_for_2030_concept_note.pdf

Öztürk, A., & Korkut, F. (2023). Design thinking customized to support STEM teachers: Co-developing and implementing STEM activities for fifth graders in Turkey. *International Journal of Technology and Design Education*, *33*(4). https://doi.org/10.1007/s10798-022-09790-x

P21. (2007). *The Intellectual and Policy Foundations of the 21st Century Skills Framework*. Retrieved November 21, 2023, from https://issuu.com/bmackenz/docs/21_century__framework

Pande, M., & Bharathi, S. V. (2020). Theoretical foundations of design thinking – A constructivism learning approach to design thinking. *Thinking Skills and Creativity*, *36*, 100637. https://doi.org/10.1016/j.tsc.2020.100637

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. BasicBooks.

Park, H., Kim, M. S., & Ifewulu, H. A. (2023). Reviewing Design Thinking in and out of Education. *Research in Integrated STEM Education*, *1*(2). https://doi.org/10.1163/27726673-bja00012

Petrillo, A., Felice, F. De, Cioffi, R., & Zomparelli, F. (2018). Fourth Industrial Revolution: Current Practices, Challenges, and Opportunities. In *Digital Transformation in Smart Manufacturing*. InTech. https://doi.org/10.5772/intechopen.72304

Poláková, M., Suleimanová, J. H., Madzík, P., Copuš, L., Molnárová, I., & Polednová, J. (2023). Soft skills and their importance in the labour market under the conditions of Industry 5.0. *Heliyon*, *9*(8). https://doi.org/10.1016/j.heliyon.2023.e18670

Rao, H., Puranam, P., & Singh, J. (2022). Does design thinking training increase creativity? Results from a field experiment with middle-school students. *Innovation*, *24*(2), 315–332. https://doi.org/10.1080/14479338.2021.1897468

Razzouk, R., & Shute, V. (2012). What Is Design Thinking and Why Is It Important? *Review of Educational Research*, *82*(3), 330–348. https://doi.org/10.3102/0034654312457429

Retna, K. S. (2016). Thinking about "design thinking": a study of teacher experiences. *Asia Pacific Journal of Education*, *36*(sup1), 5–19. https://doi.org/10.1080/02188791.2015.1005049

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Rotherham, A. J., & Willingham, D. (2009). 21st century skills: The challenges ahead. *Educational Leadership*, *67*(1).

Rusmann, A., & Ejsing-Duun, S. (2022). When design thinking goes to school: A literature review of design competences for the K-12 level. *International Journal of Technology and Design Education*, *32*(4), 2063–2091. https://doi.org/10.1007/s10798-021-09692-4

Rutland, M., & Barlex, D. (2007). Perspectives on pupil creativity in design and technology in the lower secondary curriculum in England. *International Journal of Technology and Design Education*, *18*(2), 139–165. https://doi.org/10.1007/s10798-007-9024-6

Scardamalia, M., & Bereiter, C. (2014). Education for Innovation: Beyond 21st Century Skills. *Educational Technology*, *54*(1).

Scheer, A., Noweski, C., & Meinel, C. (2012). Transforming constructivist learning into action: Design thinking in education. *Design and Technology Education*, *17*(3). https://files.eric.ed.gov/fulltext/EJ996067.pdf

Scott, C. L. (2015). The Futures of Learning 2: What Kind of Learning for the 21st Century? In *Education Research and Foresight*. https://unesdoc.unesco.org/ark:/48223/pf0000242996

Shively, K., Stith, K. M., & Rubenstein, L. D. (2018). Measuring What Matters: Assessing Creativity, Critical Thinking, and the Design Process. *Gifted Child Today*, *41*(3), 149–158. https://doi.org/10.1177/1076217518768361

Silva, E. (2008). Measuring skills for 21st-century learning. *Phi Delta Kappan*, *90*(9). https://doi.org/10.1177/003172170909000905

Spendlove, D. (2023a). Do No Harm 2.0. In S. Davies, M. McLain, A. Hardy, & D. Morrison-Love (Eds.), *The 40th International Pupils' Attitudes Towards Technology Conference Proceedings 2023*. Liverpool John Moores University. https://doi.org/https://doi.org/10.24377/PATT40.2023

Spendlove, D. (2023b). Why did design and technology education fail, and what might replace it? In A. Hardy (Ed.), *Debates in Design and Technology Education* (2nd ed., pp. 65–76). Routledge. https://doi.org/10.4324/9781003166689-7

SRI International. (2012). *21CLD Student Work Rubrics*. https://www.creatingrounds.com/uploads/9/6/2/4/96240662/21cld_student_work_rubrics_2012.pdf

Stanley, T. (2021). *Performance-Based Assessment for 21st-Century Skills*. Routledge. https://doi.org/10.4324/9781003237129

Stockard, J., Wood, T. W., Coughlin, C., & Rasplica Khoury, C. (2018). The Effectiveness of Direct Instruction Curricula: A Meta-Analysis of a Half Century of Research. *Review of Educational Research*, *88*(4), 479–507. https://doi.org/10.3102/0034654317751919

Taheri, M., Unterholzer, T., Hölzle, K., & Meinel, C. (2016). An educational perspective on design thinking learning outcomes. *ISPIM Innovation Forum*. https://hpi.de/fileadmin/user_upload/fachgebiete/meinel/papers/Design_Thinking/2016_taheri_unterholzer_ispim.pdf

Taylor, R., Fadel, C., Kim, H., & Care, E. (2020). *Competencies for the 21st century: juristictional progress*. Retrieved April 23, 2024, from https://www.brookings.edu/articles/competencies-for-the-21st-century-jurisdictional-progress/

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. In *Journal of Intelligence* (Vol. 11, Issue 3). https://doi.org/10.3390/jintelligence11030054

Trilling, B., & Fadel, C. (2009). *21st Century Skills: Learning for Life in Our Times* (1st ed.). John Wiley & Sons.

Tuckett, S. (2022). *A spotlight on Design and Technology study in England: Trends in subject take up and the teacher workforce*. https://epi.org.uk/wp-content/uploads/2022/03/Spotlight-on-DT-report_EPI-March-2022.pdf

von Mengersen, B. (2023). Thinking. In *The Bloomsbury Handbook of Technology Education*. Bloomsbury Academic. https://doi.org/10.5040/9781350238442.0017

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21 st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, *44*(3), 299–321. https://doi.org/10.1080/00220272.2012.668938

World Economic Forum. (2015). New Vision for Education: Unlocking the Potential of Technology. *New Vision for Education: Unlocking the Potential of Technology*. https://www3.weforum.org/docs/WEFUSA_NewVisionforEducation_Report2015.pdf

Yeung, W.-L., & Ng, O.-L. (2023). Using empathy maps to support design-thinking enhanced transdisciplinary STEM innovation in K-12 setting. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-023-09861-7

Zhao, K., Zhou, J., & Dawson, P. (2021). Using student-instructor co-constructed rubrics in signature assessment for business students: benefits and challenges. *Assessment in Education: Principles, Policy & Practice*, *28*(2), 170–190. https://doi.org/10.1080/0969594X.2021.1908225