Research Paper in support of the introduction of Technology

in a redeveloped Primary School Curriculum

Digital Technology—Design Thinking

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This paper sets out to examine how 'design thinking' can support teaching and learning in the curriculum area of Mathematics, Science and Technology for Stages 1 and 2 and in the subject of Science and Technology in Stages 3 and 4 as identified in the *Draft Primary Curriculum Framework* (NCCA, 2020). The document will explain the importance of design thinking to one of the competencies, *Being a digital learner*, outlining its relevance to science and technology and in particular to computational thinking, as well as its broader impact on the teaching and learning experience for both teachers and children.

The discussion will offer a definition of design thinking and explain its core principles, mindset and methodologies. A number of international case studies demonstrating the use of design thinking in primary education will be highlighted to show how these new skills and competencies can be taught, learnt and assessed. They will demonstrate the applicability of design thinking to the science and technology curriculum and how it can support both teachers and children to achieve their goals.

The last part of the paper will present recommendations for next steps on how design thinking can be developed and integrated into the redeveloped Primary School Curriculum.

1. Introduction

Being a digital learner

The *Draft Primary Curriculum Framework* (NCCA, 2020) and the *Primary Developments: Final Report on the Coding in Primary Schools Initiative* (NCCA, 2019) clearly identify the need for children to learn the necessary skills, mindset and knowledge associated with the competency, *Being a digital learner*.

Key findings from the coding report determine that teachers and school principals feel it is incumbent upon them to prepare and empower primary-aged children 'so that they are not just users of digital devices but that they can understand and be creative with digital technology to contribute to, and to change the world in which they live, for the better' (NCCA, 2019, p. 82). The report also acknowledges the anxiety felt by parents about the negative aspects of too much screen time, and that they want their children to develop awareness and understanding of how to use digital technologies and the internet responsibly and safely.

The *Draft Primary Curriculum Framework* describes digital learners as being 'curious, creative, confident and critical users of digital technology', who will be able to 'collaborate and thrive in a world increasingly immersed in technology' (NCCA, 2020, p. 9).

Designing a curriculum to cultivate this range of creative and critical attributes, coupled with the constant changes and advances in technology, presents primary schools with a serious educational challenge.

Looking beyond traditional pedagogies, design thinking offers a multi-faceted approach suited to addressing complex challenges such as the requirements of becoming a digital learner. It provides a broad and adaptable framework that includes a systemised process, a set of methodologies and adopting a particular mindset for solving complex problems in order to develop innovative solutions that remain focused on the needs of the people most affected.

The relevance and application of design thinking to primary education presents an opportunity to address the complex needs of both teachers and children as they endeavour to cope with the demands and uncertainty of teaching and learning in a digitally connected and interdependent world (NCCA, 2020, p. 8).

Evolution of design thinking

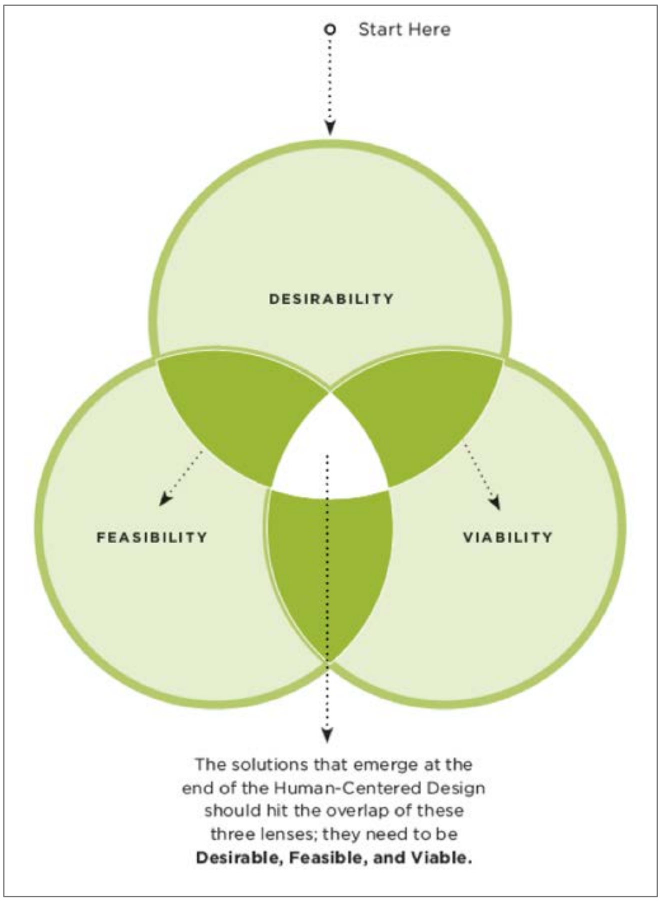
Over the last decade, design thinking has been applied across a diverse range of sectors, from business and education to local government, sport, and charities. Design thinking has become renowned as a toolset for approaching just about any context where complex and wicked problems (Buchanan, 1992) exist, brought about by the unprecedented growth and change in our digitally-transformed world.

David Kelley, founder of the design consultancy IDEO and a professor at the d.school in Stanford University, is credited with popularising and adapting the use of design thinking in business. However, design thinking has a long history of evolution from the Bauhaus (1919-33), to its application in engineering (Arnold, 1959) (Archer, 1965), architecture (Lawson, 1980), science (Simons, 1969), education (Cross, 1982), and computer science (Norman, 1988). The American design consultancy IDEO, and its leadership team, Tim Brown and Bill Moggridge, are amongst the earliest pioneers of the form of design thinking that is widely practiced today.

> *Design thinking is a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.* (Brown, 2009)

Tim Brown captured the essence of this human-centred design approach in his now famous diagram (Figure 1) showing the interdependency of what people need and want, with appropriate usable technology that can meet their needs, and a viable economic way of getting the solution into their hands (Brown, 2009).

Figure 1. Human-centred design, Tim Brown, IDEO (2009).



Design thinking, which has always been an integral part of art and design education (Cross, 2006), has also garnered wider adoption across the higher education sector in the curricula of other disciplines such as business, engineering, science, medicine and computing. Its popularity may be in part due to its promotion and publication by highly-acclaimed academics and authors such as Professor Clayton Christensen (Harvard Business School), and industry visionaries such as Steve Jobs (Apple) or Joe Gebbia (AirBnB) who have received global recognition for their design and business innovation.

Education and skills for the twenty-first century

The changing nature of the workplace calls for innovation skills, and exerts new demands on education (Davis, 2017, p. 169). This is reflected in the widely-recognised need for creativity, critical thinking and complex problem-solving skills (WEF, 2018, p. 12). Other future skills areas where demand is not matched by supply are technology, design and programming (ibid), which are deemed vital for the future economic growth and sustainability of every country.

The need to address this demand is one of the primary drivers for Ireland's *Digital Strategy for Schools 2015-2020 – Enhancing teaching, learning and assessment* (DES, 2015), which sets out the department's vision for ICT integration in Irish schools as being to:

> *Realise the potential of digital technologies to enhance teaching, learning and assessment so that Ireland's young people become engaged thinkers, active learners, knowledge constructors and global citizens to participate fully in society and the economy.* (DES, 2015, p. 5)

The recognition of the value of design thinking from economic, social, environmental, educational and technological spheres of interest has led to wider acknowledgment, at local and national government level of its impact. Ireland's most recent report by the Expert Group on Future Skills Needs (EGFSN), *Together For Design: Digital, Product and Strategic Design Skills of the Future (2020)* states the need for design literacy at all stages of education:

> *The role of both Primary and Secondary school cycles are important in creating a conducive learning environment upon which the fundamentals of design can be learned at the earliest age. The benefits of enabling young people to think critically and creatively at this early stage prepares them for the demands of Further and Higher Education level and to deal with more complex problem solving. It also encourages them to adapt more easily to a potential future of lifelong learning.* (EGFSN, 2020, p. 47)

From an education perspective, there is a growing body of literature that recognises the benefits of introducing children to a design education (Noel & Liub, 2017; Cook & Bush, 2017) with pedagogies that involve problem-based learning, human-centred creativity, prototyping, and user testing.

In a recent paper, *Design Thinking for Pre-schoolers: Encouraging Empathy through Play*, Coorey and Caldwell Rinnert (2019) note four themes that emerged from educating young children about the process of design through practical activities, making and discussion:

- brainstorming, ideation and sketching
- collaboration
- creativity and innovation
- empathy.

These themes recur in the literature as part of a set of desirable dispositions, attitudes and skills that design thinking promotes in the classroom and which are applicable in daily life into the future. In particular, the design thinking process fosters empathy—a deeper awareness of the needs and feelings of people—which is a recognised deficit in traditional STEM education (Liu Sun, 2017). Empathy helps children to be socially aware and responsible, and is *particularly important for better preparing K-12 students to effectively tackle many of the complex, human-centred, and STEM-related issues of the 21st century* (Liu Sun, 2017).

Design thinking in primary education

Other countries have already begun to integrate design thinking into the primary school curriculum, most notably the United States, the United Kingdom, Australia, Finland and New Zealand.

Stanford Professor, Shelley Goldman and Zaza Kabayadondo's book, *Taking Design Thinking to School: How the Technology of Design can Transform Teachers, Learners, and Classrooms* (2017) provides an insightful survey from a variety of contributors about the development of design and design thinking in primary and secondary education. In 2009, Goldman set up the Research in Education and Design lab (RED lab) at Stanford University to research the opportunities and challenges associated with bringing design thinking to K-12 education. The RED lab has developed, piloted and tested design thinking curricula in the classrooms of K-12 schools across America and some of these case studies are written up in the book. Of particular note, from Goldman and

Kabayadondo's many observations, is the value of design thinking to challenge traditional and limiting pedagogies which lean toward completing work in isolation, siloed subject learning, privileging of predetermined correct answers, and the pursuit of problem-solving skills often without context (Goldman & Kabayadondo, 2017, p. 78).

Their work also focuses on creating opportunities for rich STEM learning, and about understanding how design thinking coupled with technology can create access and be transformational. For Goldman and Kabayadondo, design thinking *nurtures mindsets that are consistent with 21st-century competencies such as interdisciplinary collaboration, teamwork, and active prototyping with iteration* (ibid, p. 77).

Goldman believes design thinking can help to introduce K-12 students from diverse backgrounds to engage with STEM subjects because of its emphasis on teamwork, multi-modal communication, real-world problem-solving, and the development of can-do attitudes along with creative confidence (Kelley & Kelley, 2013).

Literature on the impact of design thinking in schools is still emergent, but a few published studies are worth mentioning in this discussion.

Professor Meredith Davis of North Carolina University provides a detailed appraisal of the legacy of design in K-12 schools in her book, *Teaching Design* (Davis, 2017, pp. 155-168). Like Goldman, Davis notes the significant positive impact of design-based projects on teaching and learning. As part of a two-year study (which consulted over 900 teachers) into the impact of design in K-12 schools, commissioned by the National Endowment of the Arts (NEA), Davis published a number of critical conclusions in *Design as a Catalyst for Learning* (1997), about the benefits of design activities in the classroom:

- enhance students' flexibility in thinking skills
- strengthened approaches to creative problem-solving
- promoted self-directed learning

- increased student comfort with uncertainty
- built relationships across school subjects
- developed communication skills and teamwork
- cultivated responsible citizens. (Davis et al, 1997)

Notably, another key finding by Davis was the need for systematic and sustainable training of teachers in design thinking methods and how this approach proved to be very successful in the UK because it was adopted nationwide through systematic curriculum change under government direction (Davis & Littlejohn, 2016).

Other researchers have also determined clear benefits from the application of design thinking in the classroom. Knudsen and Shechtman (2011) conducted a 2-year randomised impact study with 30 maths teachers and almost 100 students at four middle schools from high-poverty urban districts in the San Francisco Bay Area with poor engagement and grades in maths and science. The research focused on the application of design thinking and improvisation methods to a particular aspect of the maths curriculum required for the Common Core Standards for Mathematics (Common Core State Standards Initiative, 2010), called mathematical argumentation, which the US National Science Foundation (NSF) view as a critical twenty-first century skill for teachers to develop in students.

Mathematical argumentation is based on making logical connections among abstract ideas and interacting (through discussion) with others to clarify ideas, moving students towards a clearer understanding of mathematical concepts. In addition, collaboration and connected thinking are central to both mathematical argumentation and design. Teaching mathematical argumentation requires both mathematical knowledge for teaching (MKT) and facilitation skills. The aim of the research study was to develop these skills in teachers through a Bridging Professional Development (BPD) programme funded by the NSF.

Phase one of the study involved a 3-day professional development workshop with teachers to introduce them to the different dispositions and methods of design thinking and improvisation, and how they could be applied to planning a mathematical argumentation lesson. Teachers participated in role-playing and empathy activities, where they acted out a pre-prepared lesson, so they could learn about how the students felt during the lesson and what teaching difficulties arose for them in this scenario. Over the course of the workshop, teachers collaborated in groups, researched new argumentation examples, visualised and prototyped new teaching models, role-played teacher-student interaction, and tested and iterated different responses.

Following the workshop, the researchers tracked a selected number of teachers and their classes over the course of two academic years. They also iterated the PD workshop content based on findings from year 1.

At the end of year 2, the researchers recorded improvement across two measures:

- teachers' mathematics knowledge for teaching (MKT) had increased
- students demonstrated substantial learning gains—on average gaining 10.31 points out of 36 from pre-test (at the beginning of the year) to post-test (at the end of the year).

Knudsen and Shechtman's (2015) findings from this study and those in three of their additional studies suggest that this approach can have tangible impacts on teachers' practice and their students' access to the critical high-level disciplinary practice of argumentation. They also conclude that *doing design work and facilitating mathematical argumentation can be serious fun that supports equity and the development of important skills for the 21st century* (Knudsen & Shechtman, 2015).

It is not within the scope of this paper to survey the impact of design thinking applied in primary school curricula, but the studies mentioned here by Goldman and Kabayadondo, Davis, and Knudsen and Shechtman do provide evidence of key benefits to both children and teachers.

2. Rationale

The benefits of introducing design thinking to Irish primary school, to help meet the complex demands of teaching and learning in an ever-changing technology-driven world, might be considered in relation to three core areas:

- its relevance and alignment with the attributes of science and digital technology
- as providing creative and critical problem-solving skills and methods that complement computational thinking
- as a flexible framework for building new concepts, skills, knowledge and dispositions in relation to science and digital technology.

Design thinking for a digital learner

The overarching need to create digital learners in the twenty-first century that can critically understand, create and use digital technologies safely and responsibly is identified as a key goal of the *Final Report on the Coding in Primary Schools Initiative* (NCCA, 2019).

Design thinking provides teachers and primary-aged children with a staged process and set of methods for learning:

- to research in order to gain understanding
- to think critically by reflecting on, analysing and synthesising research findings
- to generate creative ideas and to make prototype solutions, through a range of visual and maker practices
- to evaluate and test solutions with the intended audience and to iterate designs based on their feedback.

By engaging in a design thinking process in the classroom, children will learn important research and problem-solving skills by working together to share their knowledge and questions about the problem they've chosen to solve. They will learn how to break a problem down in order to understand it, by asking questions in order to find out everything they can about it. For example, what is already known and where can they get that information? Who is affected by the problem? Why, how, what do they need to find out? Who do they need to ask? In effect, they will learn key skills associated with the key attributes of being a digital learner which are described in the *Draft Primary Curriculum Framework* as:

- communicating and collaborating with others through digital technology
- accessing, analysing and managing content using digital technology
- enabling content creation, problem-solving and creativity using digital technology
- interacting ethically and responsibly with digital technology. (NCCA, 2020, p. 10)

Design thinking and computational thinking

There is a growing body of research that suggests design thinking complements and strengthens computational thinking (Lodi, 2017; Cutts et al., 2010; Maeda, 2019b; Resnick & Robinson, 2018) and that art and design should be integrated into any STEM curriculum as STEAM (Maeda, 2013). Computational and design thinking share many traits in that both are used to solve problems using a systematic and iterative approach based on research and validated by data. However, where one is analytical and data driven, based on convergent thinking, the other breaks away from pure logic, is based on divergent thinking, embracing analogy and creativity that empathises with the human perspective. STEM organises the materials, principles and processes of what and how things can be done, while STEAM includes why and by whom things are done (Yakman, 2017).

In his recent book, *How to Speak Machine* (2019), renowned tech genius and artist John Maeda warns that computational thinking alone forecasts a bleak future where machines will eventually out think us (Maeda, 2019b, p. 121). He suggests human audacity will be the distinguishing factor that keeps people in control of machines whose artificial intelligence will have long surpassed our own. Design thinking promotes audacity through the sense of agency and empowerment it gives (Clapp et al., 2017), by showing learners how to systematically break down problems, validate and re-frame them based on research findings, and how to think openly and creatively to devise and make appropriate solutions. Excellent case studies of how primary and secondary students and teachers are empowered by design thinking and making can be found at Harvard's *Project Zero*, led by Principal Investigator Edward Clapp. Projects topics range from ‘Agency by Design’ and ‘Cultures of Thinking’, to ‘Global Children’ and ‘Educating with Digital Dilemmas’.

John Maeda has dedicated his career to promoting the marriage of design and technology as the future for education (Maeda, 2013), business and innovation (Maeda, 2018).

> *But in the twenty-first century, it is design that has made computation relevant to business and, more so, to our everyday lives. Design matters a lot when it is leveraged with a deep understanding of computation and the unique set of possibilities it brings.* (Maeda, 2018, p. 11)

His latest book explains the absolute necessity for forthcoming generations to understand computational thinking, but also how these new skills must be matched with human-centred ones that focus on empathy for people, their needs and the ethical use of technology.

> *But now that computing impacts virtually everyone at the ultrafine level of their daily micromovements and at the scale of the entire world, it is more urgent than ever to know how to speak both machine and to speak humanism.* (Maeda, 2019b, p. 79).

In a practical study with 83 teachers (Liu Sun, 2015), teachers were introduced to design thinking in a three-day professional development workshop with a particular focus on empathy for teaching STEM subjects. Findings from the workshop and follow-up tracking of its application in the classroom showed a two-fold benefit from adopting an empathetic approach in STEM education—teachers used it to understand their students’ interests and the challenges they faced, and they adapted the curriculum and designed lesson plans accordingly to stimulate greater engagement. Findings showed that students were more interested in learning STEM-related subjects when the content was related to a human-centred context. In one example, ten months after the PD workshop and following in the wake of the Haiti earthquake of 2010, a teacher set students a design thinking activity to design and build a structure that would withstand the forces of an earthquake. The teacher described the activity as ‘structural engineering with a personal understanding' (Liu Sun, 2015). This example also demonstrates how primary school children can learn convergent and divergent ways of thinking to approach and solve problems using both analytical and creative skills.

One of the most ardent proponents of combining creative and computational thinking is Professor Mitch Resnick, LEGO Papert Professor of Learning Research at MIT, whose group developed Scratch, LEGO Mindstorms and a vast array of research projects focused on teaching and learning computational thinking.

Resnick believes learning within technology should be based around the 'four Ps'—projects, passion, peers and play—if children are to build their creative confidence and the necessary skills to cope with the uncertainty of a technologically-driven twenty-first century. He says that only by combining creative and design thinking with computational thinking will children to become creators and inventors of technologies, rather than consumers. Resnick calls this core mindset and approach, 'lifelong kindergarten learning' (Resnick, 2018), which is based on an iterative process of imagining, creating, playing, sharing, and reflecting, quite similar to design thinking.

This type of research and work with teachers may ultimately help to prepare school children to effectively tackle many of the 'complex, human-centred, and STEM-related issues of the 21st century' (Liu Sun, 2015).

Design thinking for teaching and learning

For teachers, design thinking also presents a clear process with key stages and associated methods that they can use to design problems and project-based learning for science and technology. It is another pedagogical approach that can be added to their repertoire. The flexibility of using a design thinking approach means it can be adapted to a specific topic, or across a number of topics in order to integrate and connect them together in meaningful real-world contexts. A range of examples of design thinking in action in the classroom can be found at Professor Goldman's RED lab at Stanford, and Harvard's Project Zero led by Edward Clapp and in other resources such as IDEO's *Design Thinking Toolkit for Educators* (2016).

The practical visual, verbal and collaborative methods used in design thinking also align closely with the constructive pedagogical approach recommended by the *Draft Primary Curriculum Framework* (NCCA, 2020) where teachers facilitate child-led activities such as research, practical application, testing and reflection. In this way, design thinking can be naturally integrated into the science and technology subject and possibly with other subjects in the curriculum. It is worth noting that as teachers receive appropriate CPD and training in how to adopt a design thinking mindset, methods and approach to teaching, this integration will happen naturally and there will be no need for design thinking to take up space in the curriculum. Rather, existing curriculum content can be taught and learnt in conjunction with other pedagogical approaches, through the collaborative, creative and critical lens that design thinking cultivates. Davis describes the application of design thinking in the service of teaching as 'strategies for teaching through design' (Davis, 2017 p. 171).

The proven benefits of design thinking in a business context (Kelley & Kelley, 2013), such as fostering team-based collaboration and negotiation, coping with uncertainty and change, and building creative skills and confidence, are also reported in the literature on design thinking as applied to education (Cook & Bush, 2017) and are therefore relevant to both teachers and children. Design thinking provides clearly-defined methods for facilitating teamwork and building consensus in a democratic and inclusive process.

3. Big ideas/Core concepts

Core concepts and competencies

Design thinking is a combination of adopting a growth mindset (Dweck, 2006), engaging in a collaborative co-operative process with multiple stakeholders and using a range of practical methodologies to solve complex problems.

The core concepts or big ideas inherent in design thinking can be discussed under three broad headings:

- **Mindset**—motivation, disposition, attitudes and values towards taking action.
- **Process**—sequence of steps or stages in a journey to achieve a goal or get to a destination/desired outcome.
- **Methods**—different types of activities and ways of doing things to achieve a goal/purpose/task.

Mindset—Dispositions and attitudes

There is a growing body of literature that suggests children's future success is not predicated on their academic output alone (Levine, 2012; Dweck, 2006; Tough, 2012). A key aspect of design thinking is cultivating dispositions and attitudes that are open to learning new things: collaborating with others, not being afraid of making mistakes and being willing to try out different strategies in order to find solutions that work. Design thinking necessitates the adoption of a mindset that enables full participation in action-based learning within a collaborative group setting, so a number of different approaches may be needed to help foster these dispositions and attitudes among school children.

The growth mindset, developed by psychology Professor Carol Dweck at Stanford University, promotes the idea that children are not limited by their natural abilities (talent) but can fulfil their potential and improve at almost anything through consistent practice and hard work. In this mindset, failure is not seen as negative, but as an opportunity to learn from mistakes which can be fixed and made better. Negative thinking such as ‘I can’t do that’ is reframed as ‘I can’t do that *yet*’. Dweck’s *power of yet* concept is the subject of her TED talk (2014) and was also popularised as a song called *The Power of Yet*, performed on Sesame Street (2013). Dweck has published widely on the subject of growth mindset (Dweck 2006; 2012), and her work has garnered increasing popularity in the American education system, especially in subjects such as mathematics (Boaler, 2016), art (Edwards, 2016) and coding (Lodi, 2017) where children often adopt a fixed mindset. In the context of a technology curriculum, and in particular computational thinking, children often decide early on whether they can code or not. However, there is a growing body of research that supports the positive benefit of adopting open dispositions and attitudes, such as Dweck’s growth mindset when learning to code (Lodi, 2017; Cutts et al., 2010).

Educational psychologist Madeline Levine (2012) suggests seven coping skills which are key for children’s development, amongst them creativity and self-efficacy (or agency). Levine also emphasises the importance of curiosity, asking questions, and the need for empathy; all of which design thinking seeks to foster through a range of human-centred research methods and ideation skills. Nigel Cross notes that design education reinforces these characteristics through its constructivist approach to education and that it can make abstract concepts in STEM more concrete through the manipulation of materials and the act of making (Noel & Liub, 2017). Developing an action-based disposition towards learning promotes engagement through the act of doing, and diminishes the fear about making mistakes through skills such as prototyping and testing which are central to design thinking. Cross identifies design thinking as a ‘multifaceted cognitive skill’ and a natural skill similar to Howard Gardener’s multiple intelligences which everyone has, not just designers (Cross, 2011). Cross describes ‘design intelligence’ as being able to switch easily between thinking and doing based on ‘deep reflection’ on problems and solutions (Cross, 2011).

Design thinking is a collaborative, human-centred process for solving problems. It is focused on the idea that a problem (no matter how complex), can be solved by a systematic approach that requires the involvement of multiple stakeholders—not just a multi-disciplinary team who may be tasked with solving the problem, but also through the inclusion of all of the people who are directly and indirectly affected by the problem.

To participate in the design thinking process, it is vital to be open to difference, to listen to the views of others, to shed any personal (or professional) bias or fixed viewpoint about how the problem may be solved, and to be willing to contribute and collaborate as part of a team. Quite often the design thinking process will begin with ambiguity, where a problem is poorly defined, and finding the way toward a solution may be difficult and uncertain. Kees Dorst (2015) describes the design mindset as one where abductive reasoning comes into play because traditional forms of reasoning, through deduction and induction which promote either a guaranteed or a merely likely conclusion based on evidence, may not be sufficient. In design thinking, abductive reasoning is used to question the what, how and who of a problem in a process: 'where unusual and interesting connections to create new 'whats' and 'hows' and test them during their iterative process' (Dorst, 2015). In the context of STEM education, curiosity to ask questions and the creativity to make unlikely connections that can lead to innovative solutions can be fostered in school children using a design thinking approach.

The core competencies of a design thinking mindset include embracing challenge and uncertainty; persisting in the face of set-backs; promoting making multiple solutions; learning from mistakes; and finding inspiration in the needs of people. Other leading proponents of design thinking (Lewrick, Link & Leifer, 2018) provide additional descriptions of the ideal mindset in *The Design Thinking Playbook* as being driven by curiosity; able to accept complexity; focused on people; able to visualise, show, experiment and iterate; able to move between analytical to creative thinking; willing to collaborate with others and to reflect carefully on actions.

IDEO's *Design Thinking Toolkit for Educators* actually defines design thinking, in an educational context, as a mindset – that is human-centred, collaborative, optimistic and experimental (IDEO, 2016). It stresses how the dynamic nature of education necessitates a mindset with a bias toward action because children's needs are ever evolving and this means a teacher's work 'will never be finished or "solved." It is always in progress' (ibid, p. 11).

> *…there is an underlying expectation that educators must strive for perfection, that they may not make mistakes…This kind of expectation makes it hard to take risks. It limits the possibilities to create more radical change. But educators need to experiment, too, and Design Thinking is all about learning by doing. In short, Design Thinking is the confidence that new, better things are possible and that you can make them happen. And that kind of optimism is well-needed in education.* (IDEO, 2016, p.11).

This resource provides an engaging introduction for teachers to the key benefits of design thinking with a clear definition of its process, methods and application in a number of classroom case studies.

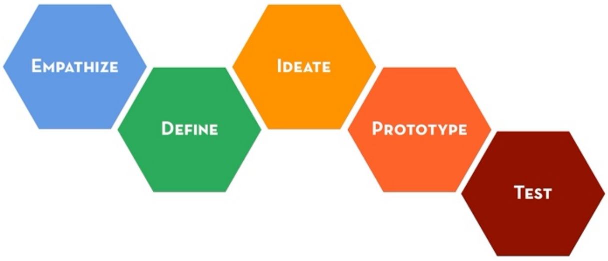
The following sections will discuss how the **process** and **methods** of design thinking can cultivate the development of a growth mindset on both sides of the teaching and learning experience.

Process

The design thinking process has evolved in various published forms over the last decade, though a couple of models (Kelley, 2009; Drew 2019) form the genesis of most, and capture the most important aspects.

The first model is the five-stage process: empathise, define, ideate, prototype and test (Figure 2); devised by Professor David Kelley at the d.school in the Hasso Plattner Institute of Design, Stanford University. The d.school has popularised this model, making it one of the most cited within the world of design thinking.

Figure 2. d.school, Stanford University, five-stage design thinking process.



The first step in this process is focused on empathy and understanding all of the issues related to a problem, in particular who is affected by it, how and why. Learning to empathise is the first key skill in understanding multiple perspectives and how deep the impact can be. This stage involves primary research in the field with all stakeholders, and secondary desk research.

The second step in the process involves analysing and synthesising all of the research gathered to date, identifying any gaps and emerging themes to focus on. Typically at this stage of the design thinking process, the original problem is reframed with a clearer human-centred definition relating to the specific target audience.

The next stage is focused on brainstorming lots of potential ideas upon which a solution might be derived. It is action-driven through sketching, discussion, and critiquing in order to identify the direction and approach for the prototype solution which will be developed in the following stage.

The prototyping phase is focused on trial and error, through making a series of prototypes that may range from low to high fidelity—for example from a sketch on paper, to a cardboard version or a 3D printed mock-up. This stage is interlinked with an iterative testing phase with real stakeholders, listening to their feedback and iterating the designed solution in response to their needs.

It is important to note that the five-stage process outlined here is not linear, but may involve iterative loops back and forth to achieve greater clarity, stay on track and ensure the final solution meets the needs of the people the problem affects.

Other forms of the design thinking process have also been widely published by the likes of the LUMA Institute, IBM, Ratford University, Institute of Design in Chicago, the British Design Council and the Neilsen Norman Group. However, most of these variants are essentially the same—proposing an iterative design process that incorporates human-centred research, problem definition, ideation, exploration, prototyping and testing. The distinguishing aspects of the design thinking process from other problem-solving approaches are its central focus on human (user, customer) needs; its collaborative nature as a team activity; its process of testing incomplete solutions with stakeholders; and iterating the design before settling on the final outcome.

It is worth reiterating the key characteristics of any design thinking process:

- It requires a **mindset that is comfortable with uncertainty**, change and ambiguity, as over the course of a design thinking project new discoveries and data will be gathered and synthesised which may dispel assumptions, redefine the problem and result in unexpected outcomes.
- It is a **team-based collaborative activity** that involves both the team working on the problem, and the range of stakeholders it affects, working together in an equitable and transparent process.
- It is **human-centred and empathetic**, focusing on why and how people are affected by the problem, by meeting, observing, talking and listening to what their needs and goals are.
- It is a non-linear **iterative process** that may require redefinition to find the right problem to solve, as well as testing and changing a range of different solutions before reaching the most appropriate outcome.
- It is **action-based and practical** requiring the team to participate in practical activities that involve:
  - **research**—interviews, site visits, observational studies, surveys, focus groups etc.
  - **ideation**—brainstorms, concept and affinity mapping, persona and journey mapping etc.
  - **design and making**—sketching, scenarios and storyboarding, physical and digital prototyping

– **testing**—creating test scripts, interviews and questionnaires for in-person/remote testing with stakeholders.

Methods

A range of both qualitative and quantitative methods are commonly used at each stage of the design thinking process. These practical methods can be broadly categorised according to the type of activity being conducted at each stage—research and definition, ideation and design, prototyping and testing etc.

Because of the diversity of the methods employed, design thinking is typically described as using a mixed methods approach. Table 1 below provides a list of some of the most popular methods applied during each stage of the design thinking process, which are combined here into four phases.

Table 1. Practical methods used at each of the four phases of the design thinking processes.

Research, understand & empathise	Define, synthesis & ideate	Design, make & iterate	Test, evaluate & reflect
Desk research Survey/questionnaire Focus groups Interviews Observational study Site visit Show 'n' tell Five whys Diary study Customer Journey (as-is) Expert interviews Parts, purposes, complexities	Brainstorming Affinity mapping Concept mapping Task analysis Thematic coding Dot voting How-might-we (HMW) problem statements Jobs-to-be-done (JTBD) problem statements Data visualisation Presentation	Sketching Customer journey (to-be) Scenarios Storyboards Crazy eights sketching Design mock-ups Paper prototypes 3D prototypes Digital prototypes	Design test Test script Participant recruitment Pilot testing Application of measurement scales (various) Talk aloud protocol Post-test survey Post-test interview Data visualisation Critical reflection Presentation

This list is by no means exhaustive: as design thinking continues to evolve, new and alternative variations of existing methods emerge from other disciplines. Design thinking is an interdisciplinary practice and the methods used reflect this, ranging from data gathering, to sketching, making and testing.

A consolidated discussion of design thinking methods applied in the classroom can be found in Chapter 7: *Pedagogical Strategies for Teaching Through Design* (Davis, 2017), where Davis clusters types of activities into:

- scenario (challenge, context, stakeholders, activities, goals)
- personas (example and roleplay, empathy mapping)
- analogical thinking (make the strange familiar, compare it to something, like an…)
- visualisation (concept mapping, modelling and diagramming, sketching, storyboards
- simulations and prototypes (paper, digital, 3D etc.)
- competing constraints—the design brief reframed based on research findings. (Davis, 2017, p. 171)

IDEO's *Design Thinking Toolkit for Educators* (2016) also provides an introduction to many of these methods and includes workshop plans and activity sheets that can be completed in class.

For design and making methods, two sources provide in-depth research, pedagogical approaches and practical activities for the classroom. Boston researcher Jill Hogan's book, *Studio Thinking from the Start: The K–8 Art Educator's Handbook* (Hogan et al., 2018), presents a detailed practice-based creative framework that spans from instruction on craft-based techniques to self-reflection and peer evaluation. It presents seven studio habits—engage and persist, envision, express, observe, reflect, stretch and explore, and understand art worlds—as well as studio structures for teachers and students to present, discuss, analyse, evaluate and iterate the work made in class. These methods align very well with the design thinking process.

Another excellent source of practical methods for the design and making phase of design thinking, is *Maker-Centered Learning: Empowering Young People to Shape Their Worlds* (2016) by the Harvard Project Zero (PZ) team (Clapp et al., 2016), which identifies practices and ideas that define maker-centred learning, and introduces the focal concepts of maker empowerment and sensitivity to design. The PZ and Agency by Design websites have produced a large volume of teaching resources that provide detailed activities and frameworks to steer children (of all ages) through critical and creative thinking routines which can be applied to just about any subject.

They are too numerous to discuss here, but two examples—the *parts, purposes, complexities* exercise, and the *artful thinking palette*—demonstrate how it is possible to make seemingly-difficult cognitive tasks, such as critical and creative thinking, both easy and engaging to do in the classroom.

4. Design thinking applied in the classroom

The application of design thinking in the primary school curriculum is gaining momentum, with a range of examples published by the previously-mentioned researchers, Professor Goldman's RED lab; the d.school and K-12 Lab, both at Stanford University; Mitch Resnick's Lifelong Kindergarten and Scratch Projects Group at MIT; Jill Hogan's Studio Thinking research at Boston College; and Edward Clapp's team Agency by Design and Project Zero, at Harvard University. A detailed review is beyond the scope of this paper but a couple of examples will be discussed here to demonstrate the type of learning experiences, skills and assessment methods that can be deployed in the classroom.

The City X Project *(*age 8–12)

The *City X Project*, designed by IDEO and based on the d.school's process, is a design thinking and problem solving workshop for children aged 8–12. It is aligned with the US Common Core State Standards and it uses emerging technologies, such as 3D modelling and printing, to inspire children to invent solutions that solve world problems.

The workshop uses a scenario set in the not-so-distant future, where Earth has sent a group of travellers to create a colony on a distant planet to build their inaugural city, City X. However, as time has gone on, they have identified common challenges and social problems that affect all of the Citizens, and stand in the way of building a thriving city.

To help them solve these problems, related to health, safety, communication, transportation, etc., the children roleplay young inventors who are enlisted to help. In order to do so, they must learn about the Citizens, get to know their challenges, brainstorm solutions, and ultimately design inventions that the Citizens of City X can build using the 3D printers they have brought with them.

The children work in collaborative teams of 3-4, following the d.school process—empathise, define, ideate, design, prototype, and test in a workshop setting. The children conduct research using a range of methods such as interviewing and observation, which they later analyse and discuss to identify key findings, using what they find out to define the problem they are solving. Then they go through a process of coming up with ideas for their solutions using brainstorming, sketching and voting techniques. The environment and mindset promoted is one of fun and play, where testing and mistakes are welcome.

Once the team have settled on an idea, they set about trying to build it: first by sketching, then making prototypes with card, paper, and other physical materials. They test each prototype with other children to observe any issues or problems with it that need fixing. At every stage, the children keep in mind the needs of the people for whom they are solving the problem, and use this as a basis to critically reflect on their progress, seeking feedback from peers as well as their teacher or workshop facilitator. They consider the good and bad implications of their invention for people and also for the environment.

Finally, they take their design to production by creating a simple 3D model on the computer, that will be 3D printed. At each clearly-defined stage of the process, the children produce outcomes which demonstrate key learning outcomes for design thinking: empathy, ethics, critical thinking, team work, growth mindset, creative thinking, visual making, self-reflection, peer-to-peer learning and evaluation. The future scenario and roleplay context of this project creates excitement (not fear) about new technologies where children can freely question and imagine what the future could be. It changes their perspective on technology from being a passive consumer to an active inventor with an important responsibility.

The City X workshop has a free toolkit available to download from the project website (http://www.cityxproject.com/) as well as a blog with posts from schools around the world sharing their learning experiences.

The Ultimate Animal Project (age 5–7)

This is a simple design thinking project run with elementary school children in the US, facilitated by design thinking evangelist, David Lee of EdTechCo. It also follows along each stage of the d.school process and aligns with the Next Generation Science Standards for Engineering and Design (US). Notably, the project encompasses science and nature with other curriculum subjects such as geography and art in a project-based learning experience. The children's task was to design the ultimate animal and to present their design to a zoo keeper, who would give them some expert feedback. A seemingly simple and exciting challenge, the children started by researching existing animals, their characteristics, abilities and needs based on the habitats where they live. They used sites like National Geographic and the World Wildlife Fund to find out all about the external parts of animals—teeth, claws, fur, skin, horns—and tried to figure out specific functions that help them to survive. This was the 'empathy and define' stage of the project. Next, the children discussed which external parts their animal must have to survive. At this stage the class wrote a problem statement to guide their decisions about what to include in their designs:

> *1C will design the ultimate animal that can survive in every environment by finding food, water and shelter.*

Then the students created as many visual drawings and sketched solutions that they could think of, which the teacher gave constructive feedback on. Reflecting on this feedback, the children revised their animal design. Following a short presentation of their design to their peers and the teacher, the children were ready to make a 3D prototype of their animal. As they made it out of clay, they learnt new techniques about modelling, size and proportions, listening to feedback from the teacher and revising their designs accordingly so their animal design was balanced and would stand up. They also learnt the technique of scoring to enable two pieces of clay to stick together. Finally they painted their models and got them ready for firing in the kiln.

In the final testing stage of the project, the children prepared a presentation using the *Explain Everything App*, an interactive whiteboarding app with screen-casting capability, to record themselves explaining their ultimate animal design. Finally the zoo keeper came into the classroom and interviewed each child about their design, giving them feedback about which parts worked and what parts might need more work. The children were able to revise their design based on this feedback.

This maker-centred learning experience, which is based on the design thinking process, enables children to learn a wide range of skills that include research and critical thinking, teamwork and collaboration, self-reflection and peer evaluation, drawing, design and planning, visualisation, 3D construction and modelling, presentation and communication, testing and how to listen to and act on feedback.

Project-based coding

Probably, one of the best examples of teaching children to code through project-based learning is *Scratch*, a jigsaw-like coding language based on snapping programming blocks together to teach children the fundamentals of computational thinking. Scratch, developed at MIT by Professor Mitch Resnick's group, is now a worldwide phenomenon, taught in thousands of schools around the world with an actively growing online community where children can share their interactive creations, stories and games and learn from each other. Learning code with Scratch also extends into the use of tangibles that include LEGO robotics and other physical computing components such as Raspberry Pi. Particularly interesting is Resnick's insistence that teaching children to code should incorporate the 'four Ps' (projects, passion, peers and play) in an iterative creative process (imagine, create, play, share, reflect) that is very similar to the design thinking process.

Too numerous to review in this paper, a wide range of project examples can be viewed at Resnick's research group's website: https://www.media.mit.edu/groups/lifelong-kindergarten/projects/.

Design thinking in Irish schools

Closer to home, there have already been a couple of formal attempts to introduce design thinking into Irish schools. In 2015, Ireland's successful bid to be the European Capital of Design for that year by Pivot Dublin, in conjunction with Dublin City Council and the National Disability Authority's Centre for Excellence in Universal Design developed a Junior Achievement Award called the *Power of Design*. The programme developed a day workshop aimed at primary schools that introduced children to the concept of design in their everyday lives, what designers do and design careers, as well as a practical design thinking exercise. The project was not continued after 2015, seemingly because it was delivered by volunteers outside the primary education sector and was dependent on short-term funding. A short report describing the project activities can be found here – https://issuu.com/pivot_dublin/docs/end_of_year_report_power_of_design.

In Northern Ireland, Patricia Flanagan and the Work West Enterprise Agency developed a pilot programme for schools to introduce children to design thinking and prepare them with skills for the twenty-first century. Piloted at CBS Glen Road for boys, and St Louise's Comprehensive College for girls, students were introduced to the design thinking process through a series of practical challenges set over an eight-week period, culminating in a local challenge on how could they improve their own school environment and experience for everyone there.

Design thinking learning outcomes

Design thinking learning outcomes are applicable across the science and technology curriculum and the process can be easily integrated with any topic. Design thinking produces a transferrable set of skills for critical and creative thinking and problem solving that empowers children (and teachers) to deal with uncertainty and be open to trying new things (including technologies).

Here is a summary of the set of skills and competencies that children can achieve and be able to demonstrate their understanding of, during and at the end of a design thinking project.

- **Critical thinking**: ability to form critical questions, be curious and use a range of quantitative and qualitative research methods. It is demonstrated by the research activities they carry out in order to find out more about the problem/topic.
- **Awareness of needs/empathy**: ability to understand multiple points of view and the perspectives of different people, to identify and understand their needs and goals. It is demonstrated by the findings gathered from doing research (with people, places, objects).
- **Identifying the right problem**: ability to analyse, synthesise, sort and organise research findings into the most important and relevant to focus on. This is demonstrated by showing how the research findings change the original problem (based on assumptions) and by writing a new problem statement.
- **Creative thinking and sketching**: ability to brainstorm and devise ideas with peers, contribute their own ideas, discuss and give feedback to others, negotiate and make decisions, express ideas in visual form, explain, communicate and present to a group.
- **Making solutions/proposals**: ability to visualise, make and build prototypes of the solution using any means available (paper, cardboard, craft materials, digital tools), to not be afraid to make mistakes, to persist, to listen, reflect and act on constructive feedback. This is demonstrated by making a number of versions from rough to fine prototypes.
- **Testing and evaluating the solutions**: ability to communicate, to listen and to reflect. This is demonstrated by asking for feedback, asking people/experts/the intended audience to try and use their solution, by recording what they say, feel, think about it, and what they would like changed or added, then acting on feedback to change/alter the design.
- **Mindset**: ability to adopt a growth mindset and engage in the 'four Ps' (projects, passion, peers, play)—to be courageous, take risks, work collaboratively with peers in a team, make mistakes and try again, communicate and listen to others, self-reflection, peer evaluation.

5. Conclusion

This paper presents a broad overview of design thinking, its core concepts, process and methods. It demonstrates its relevance to the new skills required to be a digital learner in the twenty-first century, and shows its alignment with teaching and learning technology. The scope of this paper does not include a detailed review of educational policies regarding the inclusion of design-related activities in primary school education. However, a few conclusions are presented for future consideration about how the integration of design thinking may be developed in the Irish Primary School Curriculum:

- Teachers are key to supporting the integration of a design thinking mindset, process, skills and methods into the classroom. They require training in design thinking to understand that it is not an additional subject that has to be included in the curriculum, but rather is another pedagogical teaching and learning approach for their repertoire that will empower them to solve problems and develop new innovations within their own skillset as well as that of the children they teach.
- Design thinking is particularly relevant to the science and technology strand of the curriculum but it is applicable across topics, and can act as a conceptual framework to build connections between more than one subject, facilitating project-based learning and a constructivist pedagogical approach.
- Design thinking promotes learning skills and competencies that are transferrable into other subjects and fosters lifelong learning by cultivating a curious, open mindset and individual creative confidence.
- Design thinking requires primary investment in teacher training and for prototyping materials (which may be covered under other subjects—science, technology, art) but is relatively cost effective thereafter.

- A systematic national approach to training teachers in design thinking is the most sustainable way (Davis, 2017) to ensure it is equitably developed in all schools and that all children gain these vital creative, critical thinking and making skills as identified in *the Draft Primary Curriculum Framework* (NCCA, 2020) and the *Final Report on the Coding in Primary Schools Initiative* (NCCA, 2019).
- The design thinking process can be used as a collaborative, critical and creative toolset for the NCCA and teachers to change mindsets, and to build consensus around new developments and innovation in the Irish primary school curriculum 2020-2024.
- In a process similar to that documented in the *Final Report on the Coding in Primary Schools Initiative* (NCCA, 2019), conducting a pilot project in design thinking with a small number of schools would provide further insight and learnings for its wider adoption in a national context.

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