Opportunities for Learning Design and Technology Skills and Values in the Maltese Curriculum

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Abstract

This research was motivated by the changing nature of the world around us, specifically, changes in technology, and the idea that despite this constant change, there are some underpinning commonalities such as the skills and values required to harness new technologies. The context of the Maltese education system was chosen to identify whether opportunities are present for learning these skills and values. A literature review was carried out to identify the common features of new technologies as well as the skills and values required to harness them. This was then followed by semi-structured interviews with six key experts. A thematic analysis was carried out to identify themes from the interview transcripts. Eight themes were identified: access and cost of technology, knowing your basics, technology and communities, cross-curricular learning, constructivism, mindsets (ways of thinking), types of knowledge and the digital nature of new technologies. With regards to new technologies, it was established that they are digital or supporting automation of processes, and to a lesser extent, related to or supporting a view to sustainability. A list of skills and values required to harness new technologies was compiled by using both literature and the thematic analysis. While the NCF presents many of the ingredients that are required for a sound conceptualization of technology, the links to technology education are not made due to the narrow view of technology that the NCF holds. This view sees technology as the application of science and as being composed principally of design and make activities. Thus, while the NCF presents opportunities for the conceptualization of technology as artifacts, it lacks, to differing degrees, in presenting opportunities for the conceptualization of technology as knowledge, processes and volition.

Keywords: design and technology skills, design and technology values, learning opportunities, constructionist, constructivist, design and technology curriculum, new technologies

Dedication

For my father in heaven,

My husband by my side,

My son growing inside me.

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I would also like to thank my mother, Marthese, who supported me with countless home-cooked meals and always just so happened to have a little extra to take home with me for the next day whenever I visited her. The effort did not go unnoticed, and the help went a long way. My in-laws, Josianne and John, were also a source of help and support. They provided sustenance, words of encouragement and advice inspired by their academic experiences, and in John's case, the occasional proof-reading stint.

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1 Introduction

As early as the 1950s, philosophers were already discussing the pervasiveness of technology in our world (De Vries, 2016). Humans have been engaging in technological activity for through the course of history – this kind of activity comes natural to them (De Vries, 2016). The term technology can take on various definitions. One of them is “the human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, and various kinds of natural (materials, energy) and cultural resources (money, social relationships, etc.)” (De Vries, 2016, p. 9). The key idea, therefore, is that humans engage in technological activity to fulfil their needs (De Vries, 2016). If Maslow’s (1943) hierarchy of needs is considered, one can identify technologies that satisfy needs at every level whether it’s basic physiological needs, safety needs, the need for belonging and love, the need for esteem and the need for self-actualization (De Vries, 2016).

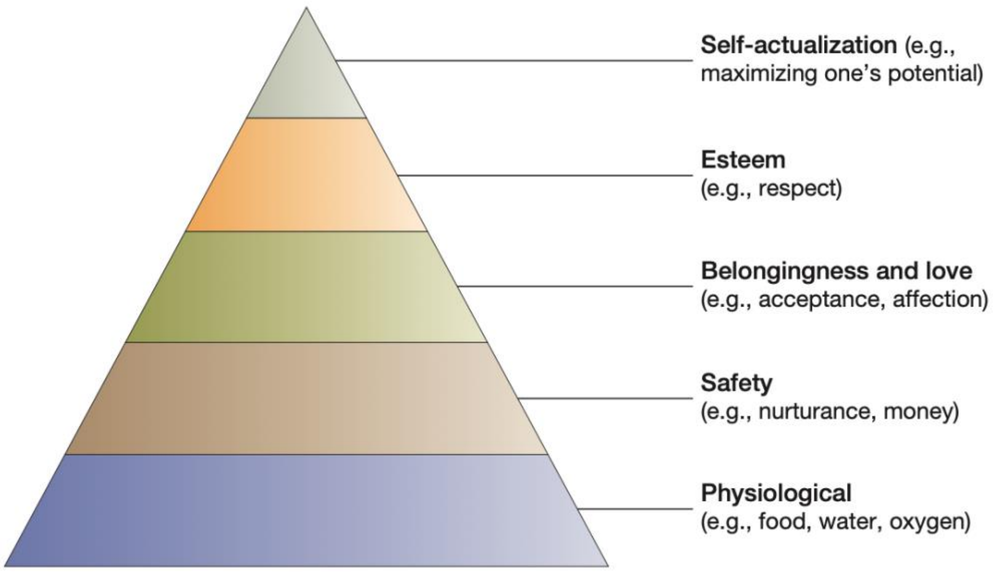

Figure 1 Maslow’s hierarchy of needs (Snowman, McCown, & Beihler, 2010; Source: Maslow, 1943)

Upon realizing these facts, the need for technology education becomes apparent. Technology education "is about creating change in the made world; about understanding the processes of change and becoming capable in the exercise of change-making" (Kimbell & Perry, 2001, p. 3). Technology education is therefore not only beneficial for students who intend to pursue their studies or a career in a field that is related to technology, but for any human being since they will be dealing with technology in all aspects of their life (professional, personal, etc.) (De Vries, 2016). All students will thus need to be skilled at making sensible, educated decisions about the way technology should be handled (De Vries, 2016). This reality provides one of the arguments for considering technology education as an essential component of general education – the personal argument (Barlex & Steeg, 2017). Barlex and Steeg (2017) debate that there are three more; an economic, a social and a cultural argument.

The curriculum has a great impact on the concept of technology that students acquire (Thomson, 1997). A sound conceptualization of technology requires opportunities for recognizing technology as artifacts, knowledge, processes, and volition (Mitcham, 1994; De Vries, 2016). Two strategies that can be employed in conceptualizing technology are case studies and concept mapping (De Vries, 2016). Case studies have been successfully used by philosophers to explain concepts of technology (De Vries, 2016). Similarly, they can be useful in explaining such concepts to students (De Vries, 2016). The use of concept mapping comes as no surprise as a useful tool in helping to develop concepts in students' minds – the tool itself is intended to visually organize and externalize the structure of concepts in one's mind, and to expose links between different concepts (De Vries, 2016). Such a tool can be particularly helpful because it visually presents concepts which are abstract and which take on different forms when applied in different contexts (De Vries, 2016).

This research attempts to establish whether there are opportunities for learning skills and values required in Design and Technology (D&T) in the Maltese curriculum. The skills and values being referred to are those that underpin the conceptualization of technology as artifacts, knowledge, processes and volition (Mitcham, 1994). The main research question is therefore:

Are there opportunities to learn these skills and values in the current Maltese Design and Technology curriculum?

Prior to answering this research question, however, two other questions need to be addressed first. These questions are:

What are the common features of new technologies in Design and Technology?

What skills and values are required to harness such new technologies?

Two sources were consulted to help answer the latter two questions. The first source is academic literature. Findings from literature are presented in the second chapter of the dissertation. The second source is experts in fields related to technology who were interviewed using the semi-structured interview tool. The interview transcripts were then analysed using thematic analysis. An overview of the research methodologies can be found in Chapter 3 and the results of the thematic analysis can be found in Chapter 4. A comparison of skills and values obtained from literature to the skills and values mentioned by the interviewed experts and identified through thematic analysis is provided in Chapter 5. A discussion of the analysis carried out on the Maltese curriculum is presented. The research questions are tackled in this chapter. Recommendations, assumptions, study limitations and concluding remarks are presented in Chapter 6.

2 Literature Review

2.1 The high rate of emergence of new technologies

Technologies change very quickly (De Vries & Tamir, 1997). This phenomenon affects people in industry who need to try to remain relevant (Majithia, 2017; Johnson, 1997). They do so by learning how to use new technologies, adapting them to the specific context and exploiting them to their full potential; all within the shortest timeframe possible. Learning a new technology is initiated with familiarization with that technology. Very often this is done in a theoretical way through reading manuals or instructions, and sometimes also in a formal way through professional development seminars or courses. At this point one begins to understand how the technology can be adapted to their situation. This is usually followed by implementation and optimization. The process is not linear, and one may need to re-visit what was learned in the theoretical learning phase to begin the optimization phase and so on, however, in carrying out these steps, the understanding of the technology deepens. New technologies will keep emerging, so the familiarization-adaptation-implementation-optimization process must be repeated every time a new technology is introduced.

2.2 Common features of new technologies

New technologies have common features such as, their digital nature and the prevalence of automation (Shanks, Booth, & Nolan, 2014). This is in stark contrast with traditional technologies which were more focused on manual work. If common features can be identified, knowing how to use one technology could serve as a good basis for learning others more quickly. As technologies evolve, so do the skill set and values needed to harness them (Majithia, 2017). Resilience, capacity for change and constant development are among the skills and values being referred to. These will enable professionals, as well as students to keep up with the fast-changing technological world. Collaboration is a skill which prepares students to work in inter-disciplinary teams which characterize many of today's work environments. Critical thinking and the evaluation of new ideas (Keith Sawyer, 2014) will help students determine whether a new technology is applicable to their situation and if it is, these two skills will also help in the optimization of its implementation. Through learning how to use a technology, students studying D&T should integrate the new knowledge into existing mental models and use the skill of interconnecting knowledge to construct an understanding of the underlying concepts of that technology (Keith Sawyer, 2014). By using the skills of integrating and interconnecting knowledge once again, and by also using the skill of pattern recognition (Keith Sawyer, 2014), students can then apply the concepts acquired while learning how to use one technology, to learn how to use new technologies. In this regard, knowing how to use a specific technology is secondary to learning the underlying concepts of that technology. For instance, knowing the logic that goes behind a computer numerically controlled (CNC) programming language is more important than knowing a specific CNC programming language since the logic can be used in a variety of languages that control a variety of automated machine tools. The curriculum should provide opportunities for students to make the conceptual leap from superficial to deep learning if students are to learn the skills mentioned above (Keith Sawyer, 2014). The aim of the D&T curriculum would be for students to be able to teach themselves and learn independently through self-learning. This approach has also been termed heutagogy (Ilieva Nikolovska, Grizev, & Iliev, 2019). Two of the most important skills to be taught would therefore be knowing where to look for information and filtering through what is relevant and what is not.

2.3 The philosophy of technology and the nature of technological knowledge

The philosophy of technology was born in the mid-1950s and as such, it is a rather young philosophical domain (De Vries & Tamir, 1997). Since technology is continuously evolving, the philosophy of technology also remains in a state of flux (Ankiewicz, De Swardt, & De Vries, 2006). The philosophy of technology asks what constitutes technology as a subject and, as a manifestation and a result of culture – the answers to these questions establish the "concepts *of* technology" (De Vries & Tamir, 1997, p. 3). The philosophy of technology also asks what concepts form the body of knowledge of technology – this establishes the "concepts *in* technology" (De Vries & Tamir, 1997, p. 3). The two types of concepts can be linked to humanity and science respectively. When speaking of "concepts *of* technology" (De Vries & Tamir, 1997, p. 3), it is important to highlight the presence of the human aspect in technology. Many believe that technological development is guided by rational decisions, however, this is not always the case (De Vries & Tamir, 1997). Technology is a result of human activity and in turn goes on to shape human activity. "Concepts *in* technology" (De Vries & Tamir, 1997, p. 3) are generally founded in science. However, scientific concepts need to be re-constructed in order to be applied to technology (De Vries & Tamir, 1997).

2.3.1 De Vries' critical and analytical philosophy of technology

From De Vries' (2005) paper about the nature of technological knowledge, where he identifies two facets to the philosophy of technology – the critical and the analytical, we can draw parallels to the "concepts of technology" and the "concepts in technology" (De Vries & Tamir, 1997, p. 3). According to De Vries, the critical side of the philosophy, seeks to understand "the role of technology in culture and society" (De Vries, 2005, p. 150). The analytical side of the philosophy encourages those engaging with technology to ask, “what do you exactly mean when you say/write…?” and therefore “has conceptualisation as its main goal” (De Vries, 2005, p. 150).

2.3.2 Ropohl’s forms of technological knowledge

Another author who made direct reference to the critical aspect of the philosophy of technology is Ropohl (1997). He mentions that one type of technological knowledge is socio-technical understanding (Ropohl, 1997). According to him, other forms of technological knowledge include technological laws, functional rules, structural rules and technical know-how (Ropohl, 1997).

2.3.3 Conceptual and procedural knowledge – Bayazit, McCormick and Ryle

Other authors have created their own categories of technological knowledge. Some, established broad views of knowledge categories and chose to categorize technological knowledge into declarative and procedural (Bayazit, 1993), or conceptual and procedural (McCormick, 1997), in support of Ryle’s (1949) ‘knowing that’ and ‘knowing how’. Conceptual knowledge is knowledge of facts – one example of conceptual knowledge is the knowledge of scientific or natural phenomena. Procedural knowledge is the knowledge of processes. Knowing how to ride a bicycle is an example of procedural knowledge.

McCormick (1997) makes provision for the fact that the terms conceptual and procedural are not representative of all kinds of knowledge in technology and laments that the two types of knowledge are often regarded as separate and the relationship between the two is ignored. He also justifies why he prefers to use the term conceptual instead of declarative for his knowledge category (McCormick, 1997).

Cognitive psychologists usually like to use the terms declarative and procedural to distinguish “knowledge of facts” (Anderson, 1990, p. 219) from knowledge of processes (McCormick, 1997). This is problematic on two levels for conceptual knowledge in technology. First, in technology, conceptual knowledge also includes knowledge of relationships between facts (McCormick, 1997). Second, it paints declarative knowledge as inert knowledge, when we know that conceptual knowledge in technology is often part of an active process (McCormick, 1997). Due to the pervasive presence of technology in our lives, technological knowledge borrows and connects knowledge from various subjects or domains (McCormick, 1997). McCormick (1997) states that the scientific knowledge that is borrowed, transformed and put to use in technologies is a part of the conceptual knowledge relevant to technology (Ankiewicz, De Swardt, & De Vries, 2006). Conceptual knowledge, as defined by McCormick (1997), is made up of two types of knowledge “… that drawn from other subjects… and that unique to technology” (McCormick, 1997, p. 153).

The other type of technological knowledge identified by McCormick (1997), is procedural knowledge. “Design, modelling, problem solving, system approaches, project planning, quality assurance and optimisation are all candidates for technological procedural knowledge and can be found across many technologies whatever their specific context” (McCormick, 1997, p. 144). McCormick (1997) here comments on the extent to which these types of knowledge can be transferred to different contexts and whether for example, problem-solving in one context is the same as in another thus introducing the idea of situated cognition. He argues that problem-solving is contingent upon knowledge in the field of the problem (Glaser, 1984 & 1992) which means that while we may be able to use a general problem-solving procedure learned during one successful problem-solving activity, in another problem-solving activity, we may still fail to solve the problem if we do not have sufficient domain knowledge.

Delineating a distinctive set of procedures or concepts that constitute technological knowledge is impossible since situations encountered when engaging in a design process are unpredictable (McCormick, 1997).

Several of the authors who classify technological knowledge in conceptual and procedural categories also acknowledge a third type of knowledge which serves as either a link or as a control function over the use of conceptual and procedural knowledge (McCormick, 1997). Gott (1988) calls it ‘strategic knowledge’ and McCormick (1997) describes it as the kind of knowledge that enables us to decide what to do and when to do it – or in fewer words metacognition or self-regulation. This kind of knowledge involves “planning what to do next, checking outcomes of strategies, and evaluating and revising strategies” (McCormick, 1997, p. 147).

Schoenfeld (1985) simply calls this category of knowledge ‘control’ since its function is to control conceptual knowledge and heuristics which are loosely linked to procedural knowledge.

The nature of strategic knowledge is tacit. This means that it may be difficult for teachers to realise that they have this kind of knowledge and that they need to teach it. It is also difficult for students to realise that this knowledge exists and that they need to acquire it to control the other types of knowledge. It is therefore imperative that educators make such efforts to teach this kind of knowledge explicit. The explicit treatment of strategic knowledge makes it easier for students to acquire and to subsequently transfer it to new and different contexts (McCormick, 1997).

2.3.4 Mitcham's manifestations of technology

Mitcham's book, titled 'Thinking Through Technology – The Path between Engineering and Philosophy' (1994) starts off by examining the historical traditions of the 'engineering philosophy of technology' and the 'humanities philosophy of technology'.

For him the distinction between the two is that the former sees technology as being so pervasive that the engineering method is the only way to tackle problems in every aspect of life (Mitcham, 2001). Mitcham here uses Billy V. Koen's[1] view as an exemplar of this type of philosophy of technology, and says that for him, "the only alternative is whether we use the engineering method consciously or unconsciously" (Mitcham, 2001).

On the other hand, the humanities philosophy of technology, while acknowledging the importance of technology, posits that "not everything is a technology" and that there are therefore "other legitimate forms of knowing, acting, and being in the world than the technological way" (Mitcham, 2001).

Mitcham (1994) then takes an interesting perspective on the philosophy of technology – he attempts to explain technology through the ways it manifests itself. He argues that technology manifests itself in four ways, these are objects, knowledge, activity and volition (Mitcham, 1994). Some of these manifestations are quite easy to understand while others offer a bigger challenge. For example, technology manifests itself as objects such as tools and machines (Mitcham, 1994). The examples he uses here are intended to show that there is a range of objects having different characteristics and complexities through which technology manifests itself.

[1] Billy V. Koen is a Mechanical Engineering Professor at the University of Texas at Austin, he has received several awards for his contribution to engineering and engineering technology education (IEEE, 2005).

Maxims, rules and theories are the manifestation of technology as knowledge – they are the types of knowledge that are activated in the process of creating an object (Mitcham, 1994).

The process of creating an object itself then, is one of the manifestations of technology as action or activity (Mitcham, 1994). The antecedent to the creation of an object is usually the designing of the said object where the design methodology is employed (Ankiewicz, De Swardt, & De Vries, 2006). Other manifestations of technology as action or activity include using and maintaining the object (Mitcham, 1994).

The last type of manifestation of technology discussed by Mitcham (1994) is volition. Mitcham states that this dimension is often overlooked and describes it as "the will that brings knowledge to bear on the physical world to design products, processes, and systems" (Mitcham, 2001).

Mitcham (2001) emphasizes that if we were to analyse different technologies, we would not find all the manifestations present in equal amounts (Mitcham, 2001).

2.3.5 Simon's essential design knowledge base for the training of designers

Simon (1996) links classic design methodology to problem-solving theories from computer science and psychology (Ankiewicz, De Swardt, & De Vries, 2006) and summarizes the topics in the theory of design (see Table 1). He justifies the link he makes between engineering, computer science and psychology by saying that "all who use computers in complex ways are using computers to design or to participate in the process of design" (Simon, 1996, p. 137) and therefore, the fact that people from different fields are all using computers in the same way – to participate in the design process – gives a common ground for interactions between different disciplines. As an example, he mentions that it is very unlikely for an engineer and a composer to have a meaningful dialogue about each other's work (Simon, 1996). However, a meaningful conversation about design is very possible since design is a common creative endeavour for both (Simon, 1996). He ends chapter 5 of his book by saying that for a liberal education to be complete, the science of design must be studied as a core discipline and should not just be regarded as a component in a technical education (Simon, 1996). This is also because design science aims at generating and communicating knowledge that is pertinent to the whole research community or the global practice rather than to a single individual (Johannesson & Perjons, 2014).

Table 1 Summary topics in the theory of design (Simon, 1996, p. 134)

Topic	**Sub-topic**	**Description**
The evaluation of designs	Theory of evaluation	Utility theory, statistical decision theory
	Computational methods	Algorithms for choosing *optimal* alternatives such as linear programming computations, control theory, dynamic programming
		Algorithms and heuristics for choosing *satisfactory* alternatives
The formal logic of design		Imperative and declarative logics
The search for alternatives	Heuristic search	Factorization and means-ends analysis
	Allocation of resources for search	
Theory of structure and design organization		Hierarchic systems
Representation of design problems		

2.3.6 *Vincenti's six categories of engineering design knowledge*

Vincenti (1990) identifies six categories of engineering design knowledge based on his study of the field of aeronautic engineering. These are fundamental design concepts (operational principles and normal configurations), design criteria and specifications, theoretical tools (mathematics, reasoning, laws of nature), quantitative data (which he further splits into descriptive and prescriptive), practical considerations and design instrumentalities (Vincenti, 1990). These categories interact closely with each other.

Ankiewicz et al (2006) have also identified sub-categories and given a short description for each as shown in Table 2.

Table 2 Vincenti's categories of engineering design knowledge (Ankiewicz, De Swardt, & De Vries, 2006, pp. 122-123)

Categories	**Subcategories**	**Description**
Fundamental design concepts	Operational principles (are prescriptive)	How the device works
	Normal configurations (are prescriptive)	The general shape and arrangement to best embody the operational principle
Criteria and specifications	Knowledge of the technical criteria appropriate to the device and its use	
	Assignment of the values or limits to those criteria	
	Translation of the qualitative goals of a device into concrete technical terms	

Categories	Subcategories	Description
Theoretical tools (precise and codifiable)	Mathematical methods and theories (are descriptive) (simple formulas for direct calculation or more complex calculative schemes)	Scientific end of spectrum – pure mathematics tools having no physical content in themselves
		Mathematically structured knowledge that is essentially physical
		Theories based on scientific principles
		Phenomenological theories
		Quantitative assumptions introduced for calculative expedience
	Intellectual concepts (provide the language for conceiving and analysing artefacts)	Basic ideas from science
Quantitative data	Descriptive knowledge (knowledge of how things are)	Physical constants, properties of substances and physical processes
	Prescriptive knowledge (knowledge of how things should be to attain a desired end)	Process specifications issued by manufacturers
		Safety of players prescribed by government agency
Practical considerations (derived from experience in practice – mostly learned on the job)	Experience in design (including tragic experience)	
	Design rules of thumb	
Design instrumentalities	Structured procedures	Division of an overall system into subsystems

Categories	Subcategories	Description
		Optimisation ('satisficing' is not the very best solution but one that was satisfactory)
	Ways of thinking (thinking itself is a mental process; knowing how to do it is an aspect of the tacit knowledge)	Thinking in terms of analogies
		Non-verbal thinking
		Visual thinking
	Judgmental skills (include an ability to weigh technical considerations in relation to the demands and constraints of a social context, is mostly tacit and can be learned only through practical experience)	

2.3.7 De Vries' alternative to Vincenti's categories of technological knowledge

In his 2003 paper, also about the nature of technological knowledge, De Vries offers an alternative to Vincenti's (1990) categories based on his case study of the development of a technology for the creation of integrated circuits and transistors, called LOCal Oxidation of Silicon (LOCOS) at the Philips company. He identifies the following categories (De Vries, 2003):

- Functional nature knowledge is made up of essential design knowledge and the applicability of an item to a particular task. There is an intentional aspect to this form of knowledge. It is a form of knowledge which is more generic and that can be applied more broadly. Knowing what something is normally used for is also a form of functional nature knowledge.

- Physical nature knowledge consists of factual and theoretical knowledge of the world around us. This may include knowledge of scientific theories, knowledge of the natural world and phenomena and knowledge of the properties of materials in quantified terms.
- Knowledge of the relationship between physical and functional nature is what makes the creation of specifications and criteria possible. This in turn helps one determine the suitability of an item for the intended function. Knowledge of the relationship between physical and functional nature combines the two prior forms of knowledge and has also been called means-ends knowledge.
- Action or process knowledge is knowledge on how to carry out procedures that accomplish the required results.

Each of the knowledge categories in De Vries' (2003) model can be equated to one or more category from Vincenti's (1990) model. For example, De Vries links functional nature knowledge to fundamental design concepts and practical considerations from Vincenti's (1990) model. Physical nature knowledge (De Vries, 2003) is linked to theoretical tools and descriptive quantitative data (Vincenti, 1990). Means-ends knowledge (De Vries, 2003) is linked to prescriptive quantitative data as well as design criteria and specifications (Vincenti, 1990) while action or process knowledge (De Vries, 2003) is linked to design instrumentalities and theoretical tools (Vincenti, 1990). This has been illustrated in Figure 2.

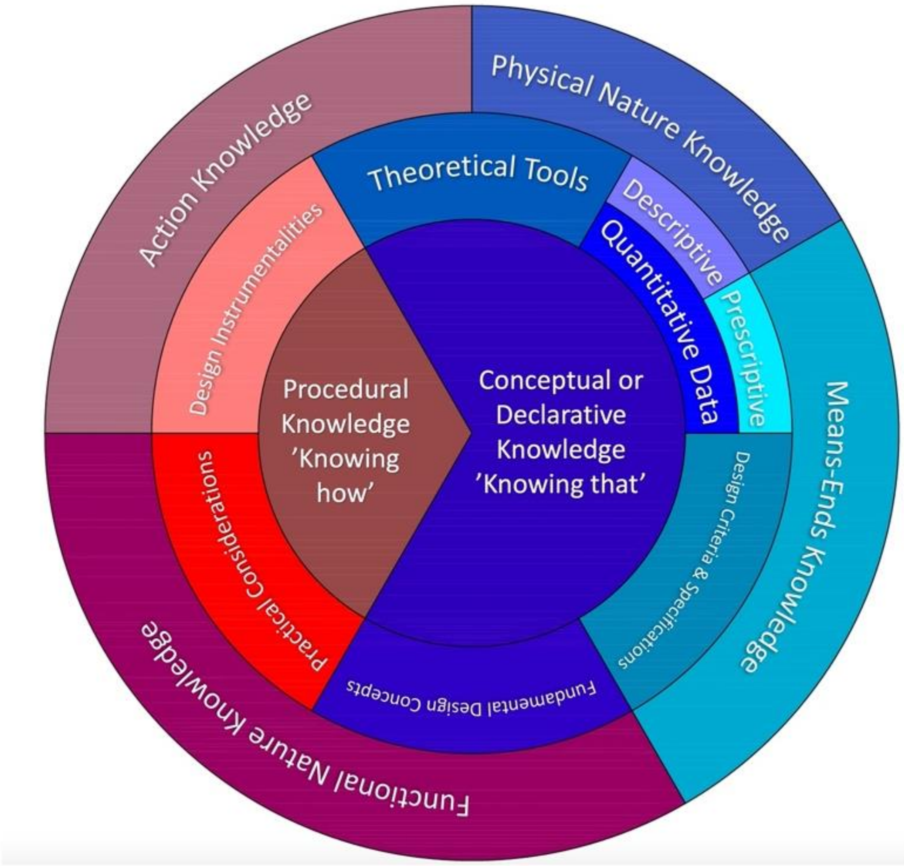

Figure 2 Categorizations of technological knowledge showing binary models (Bayazit, 1993; McCormick, 1997; Ryle, 1949) in the centre circle, Vincenti's (1990) model in the first level around the centre circle and De Vries' (2003,2005) alternative to Vincenti's (1990) model in the outer ring.

Through his alternative knowledge categories, De Vries (2005) shows that only means-ends knowledge has a propositional nature and is thus somewhat like knowledge in the sciences. He further elaborates on the fact that some technological knowledge does not fit into the traditional views of knowledge, as the latter require knowledge to satisfy the three conditions of propositional knowledge (De Vries, 2005). These are truth, belief and justification. Some forms of knowledge in technology, like physical nature knowledge, functional nature knowledge and action knowledge, cannot be expressed in propositions as they have a normative nature (De Vries, 2005).

2.3.8 The normative nature of some forms of technological knowledge

Propositional knowledge requires belief, truth, and justification to hold. Technological knowledge presents two issues to this view of knowledge (De Vries, 2005). Knowledge in technology cannot always "be expressed in propositions" (De Vries, 2005, p. 151) and "there are types of propositional knowledge that cannot adequately be associated with truth, because they do not refer to an actual state of affairs" (De Vries, 2005, p. 152). Even if we could speak of truths when it came to technological knowledge, the focus would be effectiveness and not the truth of prescriptions (De Vries, 2005).

In science, when one acquires knowledge about a physical phenomenon, one cannot say that "it is good or bad" (De Vries, 2005, p. 152), however, with technology, one can say whether a function is fulfilled well or not (De Vries, 2005). Due to this, the belief that was held in the past that technology is the application of science, has now been discarded (De Vries & Tamir, 1997). This normative component of technological knowledge needs to be taught to D&T students. This requires teaching how to make "judgments with respect to the function and functioning of technological artefacts" and teaching "norms, standards, rules of thumb" and other types of normative technological knowledge (De Vries, 2005, p. 153).

2.4 Technology education, constructivism and constructionism

Given how quickly the world is changing and the high rate of emergence of new technologies, technology education can no longer merely be the teaching and learning of manual skills but also needs to expose students to the "concepts *of* technology" and the "concepts *in* technology" (De Vries & Tamir, 1997, p. 3). The philosophy of technology can be a very useful tool in establishing what these concepts are (De Vries & Tamir, 1997).

Constructivist and constructionist theories of teaching and learning, posited by Jean Piaget and Seymour Papert respectively, lend themselves well to the teaching and learning of D&T (Han & Bhattacharya, 2001). Constructivism encourages students to engage in real-world situations and be critical of them (Han & Bhattacharya, 2001). This means that as a pedagogy, constructivism can address both the critical and the analytical side of the philosophy of technology. Through D&T, students can develop their analytical skills while engaging with problems, while investigating and attempting to address the impacts of technology on culture and society (De Vries, 2005). The sort of conceptualisation that needs to be fostered in D&T students calls for the analytical side to be emphasized more in the teaching of D&T (De Vries, 2005).

Constructivism posits that when encountering the world around us, we build representations in our minds which are compared with existing knowledge which we would have gained from previous experiences (McCormick, 1997). As a pedagogy, constructivism emphasizes the need for learning to be embedded in real-world situations where knowledge is constructed by the learner (Han & Bhattacharya, 2001) and learning of new concepts by students is done through the “reconstruction of existing concepts that pupils have already acquired” (De Vries & Tamir, 1997, p. 7).

In the field of technology, social constructivism, as a philosophy, can help describe how several different human factors affect whether a technology is regarded as an accomplishment or not (De Vries & Tamir, 1997).

Situations in the real world are very different from the idealised situations presented in science where gases are ideal, movement is frictionless, etc. (De Vries & Tamir, 1997). Hence through science, students are not just engaging in a process of constructing knowledge, but they are also being introduced to the way things are done in science and the language that is used in science (McCormick, 1997). This cultural aspect of learning is also included in the notion of social constructivism – through learning science, students are also being socialized into the science community (McCormick, 1997).

According to McCormick (1997), constructivism has three main consequences for how conceptual knowledge is used and developed in technology education.

1. When a D&T task requires scientific knowledge, the fact that students may have already encountered the concept in science makes it difficult to understand what prior knowledge students have.
2. Concepts brought from the science classroom into D&T lessons might not be applicable in the situation of a technology project. This point is also emphasized by De Vries and Tamir (1997) who add that while scientific concepts are important in D&T, they need to be transformed into intermediate concepts which bridge between reality and scientific theories.
3. Comprehension of new concepts illustrated in the D&T classroom will take time.

These consequences result in questions relating to the construction of concepts, which include (McCormick, 1997, p. 153):

1. What knowledge is needed when dealing with a specific technology task?
2. What prior knowledge students have?
3. What level of support is adequate for conceptual development within technological project activity?

Very often the pressure to design and make products does not leave enough time for activities that are intended to identify the concepts needed, and the knowledge that students already have, and develop them in the context they are intended to be of use (McCormick, 1997). This also presents a problem for transfer of knowledge; students do not develop situated cognition when they do not engage with and realise the intimate relationship between an object, its associated action and the context it is intended to be used in (McCormick, 1997).

When teaching designing and problem-solving – two examples of procedural knowledge – McCormick (1997) highlights the importance of making the instruction explicit. This needs to be done on two levels of knowledge – the specific and the strategic levels (McCormick, 1997). At the specific level we can take an individual step of the design process and teach techniques that help deal with it (McCormick, 1997). For example, if we are teaching students how to generate ideas to solve a problem, we need to give explicit instruction on a range of methods that can be employed, such as brainstorming and morphological analysis (McCormick, 1997). At the strategic level, students need to face such issues such as when to stop generating ideas or when to start over by looking at the problem from a different perspective (McCormick, 1997). Explicit instruction at the strategic level is akin to the cognitive apprenticeship method (Pritchard & Woollard, Pedagogy: the rules, principles and theories that guide current practice, 2010). Planning lessons of a duration that coincides exactly with the steps of the design process, takes this opportunity away and encourages the notion that the design process is a ritual or a set of steps that are followed every time (McCormick, 1997). It also takes away from the role of agents that students have in their design process as they are not able to make these decisions for themselves and engage in strategic thinking (McCormick, 1997). A good way to show these behaviours explicitly is for the teacher to engage in designing a product themself and thus model the behaviour for students (McCormick, 1997). Alternatively, a design case study can be used (McCormick, 1997).

Through the creation of an artefact, students create, reflect upon and share ideas – this is the premise of constructionism (Han & Bhattacharya, 2001). According to Papert (1993, p. 3):

> *"The word with the v expresses the theory that knowledge is built by the learner, not supplied by the teacher. The word with the n expresses the further idea that happens especially felicitously when the learner is engaged in the construction of something external or at least sharable".*

Thus, constructionism builds upon constructivism and still acknowledges the learner as the one who constructs their own knowledge, it is therefore also a student-centred approach (Han & Bhattacharya, 2001). It also recognizes the importance of embedding learning in real-world situations to make learning meaningful (Han & Bhattacharya, 2001). However, constructionism emphasizes the creation of an external artefact that can be shared as the means through which the construction of knowledge can be made tangible, especially if the artefact is presented to peers and the process that the students underwent to create it – the understanding and thoughts – are made explicit to others (Han & Bhattacharya, 2001). This is also in line with the approach of heutagogy where successful learning is measured through presenting the acquired knowledge to the teacher for evaluation (Ilieva Nikolovska, Grizev, & Iliev, 2019).

The role of the teacher in this kind of learning environment is that of facilitator or guide (Han & Bhattacharya, 2001; Ilieva Nikolovska, Grizev, & Iliev, 2019). The teacher assigns tasks through which students learn investigation skills, creativity and problem-solving (Han & Bhattacharya, 2001). The learning outcomes associated with tasks or activities should be made clear to students from the beginning as it helps students understand what they are trying to learn and the level at which they need to learn it (Han & Bhattacharya, 2001). Guiding students in the use of various strategies is in line with presenting content in a variety of ways (Han & Bhattacharya, 2001; Pritchard & Woollard, Pedagogy: the rules, principles and theories that guide current practice, 2010; CAST, 2018). Allowing them to choose which strategy to use ensures that they are given multiple means of solving the problems they are facing and builds further on this (Han & Bhattacharya, 2001; CAST, 2018). These two measures lead to students taking responsibility for their learning (Han & Bhattacharya, 2001). Presentations and discussions followed by feedback from both the teacher and peers help learners revise their projects and improve them (Han & Bhattacharya, 2001).

There are obviously difficulties in implementing such a learning environment and these stem from different variables which make up this approach. The first, and probably most obvious variable, is the teacher. Every teacher will have their own views and therefore must always remain aware of their biases (Han & Bhattacharya, 2001). They must also be careful to balance their role of facilitator with their role of disseminating knowledge (Han & Bhattacharya, 2001). Different instructors will also have different schedules and strategies as will different classrooms (Han & Bhattacharya, 2001).

The classroom, and its individual learners give rise to the second set of variables – each learner has their own preferences and since they will each construct their own understanding of the design process, what is conceived as the design process in one student's mind may not be the same as that conceived in another student's mind (Han & Bhattacharya, 2001).

Due to the ill-defined and open-ended situations which the D&T learning environment presents to students, assessment provides another challenge (Han & Bhattacharya, 2001). This is further complicated by the fact that students will have been presented with and will have chosen different strategies to deal with their problems (Han & Bhattacharya, 2001).

Project-based learning (PBL), which is based on constructivist and constructionist educational models, and serves to improve students' design, modelling, cross-curricular and problem-solving abilities (among others) is a specific tool in the constructionist toolbox that can be used to teach D&T (Han & Bhattacharya, 2001) as it addresses the concepts present in both conceptual and procedural knowledge described by McCormick (1997). It is also a method that is well suited to novice learners which is often the case with secondary school students (the approach can become more self-directed and guided by experience as learner expertise increases) (Hägg & Kurczewska, 2019).

This type of approach is generally characterized by a project which extends over a significant period – usually more than a few lessons and up to a full term or semester (Han & Bhattacharya, 2001). Students are expected to be self-directed while working on the project and the product developed is meant to be realistic and significantly tackle the scenario originally presented (Han & Bhattacharya, 2001). Overall, the PBL process should include "authentic content, authentic assessment, teacher facilitation but not direction, explicit educational goals, collaborative learning, and reflection" (Han & Bhattacharya, 2001, p. 11).

Han and Bhattacharya (2001) identify seven key components of PBL:

1. Learner-centred environment: decisions and choices are made by the student with advice given throughout such that modifications can be made. The process should be documented to serve the purposes of assessment as well.
2. Collaboration: the project can include group decision-making and interdependent aspects.
3. Curricular content: certain project decisions should be based on recognized standards and goals should be made clear.
4. Authentic tasks: the project should be connected to the real world and issues which are relevant to students.
5. Multiple expression modes: allowing students to express themselves in various ways also means that they can learn to use different technologies for presenting, planning and developing their work.
6. Emphasis on time management in all aspects of the project.
7. Innovative assessment: assessment should be an ongoing process of documenting learning. A variety of assessment methods including teacher assessment, peer assessment, self-assessment, and reflection should be used.

Learning by design (LBD) is another constructivist approach (Van Breukelen, De Vries, & Schure, 2017). In LBD, the focus is to solve authentic problems collaboratively, to engage in critical reflection and to learn conceptual knowledge as the need arises (McLaren, 2012; Van Breukelen, De Vries, & Schure, 2017). Expert designers engage with design tasks in this way – they focus on identifying what knowledge is needed to solve design problems because they already have the procedural knowledge (Van Breukelen, De Vries, & Schure, 2017).

As with many other approaches, LBD requires guidance from the teacher to avoid having students focus on the 'making' aspect of the project at the cost of acquiring new conceptual knowledge (Van Breukelen, De Vries, & Schure, 2017). Students tend to attempt to solve the problem at hand with whatever limited scientific knowledge they have because they are already cognitively engaged with procedural knowledge (Van Breukelen, De Vries, & Schure, 2017). The designs created end up being a product of guesswork and due importance is not given to conceptual knowledge (Van Breukelen, De Vries, & Schure, 2017). Students only give attention to conceptual knowledge if they feel that it is necessary to achieve the result they intended in their design and may still have gaps in their conceptual knowledge or shortcomings in the way it is applied (Van Breukelen, De Vries, & Schure, 2017).

The role of the teacher, therefore, is to be a facilitator of the process and to be central but "not at the centre" (McLaren, 2012, p. 4; Van Breukelen, De Vries, & Schure, 2017). Some concrete examples of how the teacher can do this are:

- Aiding students with strategic decision-making (Kolodner, 2002)
- Helping students identify inter-connection between fields of knowledge (McCormick, 1997)
- Not intervening unnecessarily (Murphy & Hennessy, 2001)
- Resist the temptation to offer up solutions when they feel that the student does not have the necessary knowledge to come up with ideas (McCormick, 1997)

- Make teaching explicit when teaching all kinds of skills and knowledge be it metacognitive skills (McLaren, 2012), strategic knowledge (McCormick, 1997) or conceptual knowledge (Van Breukelen, De Vries, & Schure, 2017)

Aspects of the strategies discussed can help teach D&T successfully and lead the learner to being able to identify what knowledge they require to solve assigned problems (McLaren, 2012). The teacher merely guides or indicates where the required knowledge may be found and can therefore be seen as facilitator, “enabler” or “choreographer of improvised learning” (McLaren, 2012, p. 4). While the idea of improvised learning may sound daunting to teachers as it is not possible to prepare for that which one does not know is going to be required, this type of learning is very similar to the way problems arise and are solved in the real-world (McLaren, 2012).

2.5 Design and technology skills and values

The design process and problem-solving are skills identified as being essential to D&T and to be learnt through D&T (McCormick, 1997). Modelling, system approaches, project planning, quality assurance and optimization are also skills that can be useful when engaging with technology (McCormick, 1997). McLaren (2012) also adds self-evaluation, decision-making, designerly thinking, critical thinking, making value judgments and taking intellectual risks to the list.

Lucas and Hanson (2014) conducted a study with engineers and engineering educators. One of their main findings was that engineers are driven by making “things that work” or making things “work better” (Lucas & Hanson, 2014, p. 4). They also identified six engineering habits of mind (EHoM) and summarized them as shown in Table 3. In addition to the EHoM, Lucas and Hanson (2014) also emphasized the importance of learning habits of mind and represented their findings as shown in Figure 3.

Table 3 Engineering Habits of Mind (Lucas & Hanson, 2014, p. 4)

Centre for Real-World Learning (CRL) Engineering Habits of Mind	
Systems-thinking	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognising interdependencies, synthesising
Problem-finding	Clarifying needs, checking existing solutions, investigating contexts, verifying
Visualising	Move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping
Creative problem-solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a 'team sport'
Adapting	Testing, analysing, reflecting, re-thinking, changing (physically and mentally)

Johnson (1997) emphasizes that while "memorization of important information, development of motor skills, understanding concepts and relationships, and enhancement of intellectual skills such as problem solving and decision making" (p. 177) are important, the advancement of technology requires more emphasis on deeper understanding and intellectual skills. He concludes that the social constructivist learning theories are required for instruction to be successful at imparting these skills (Johnson, 1997).

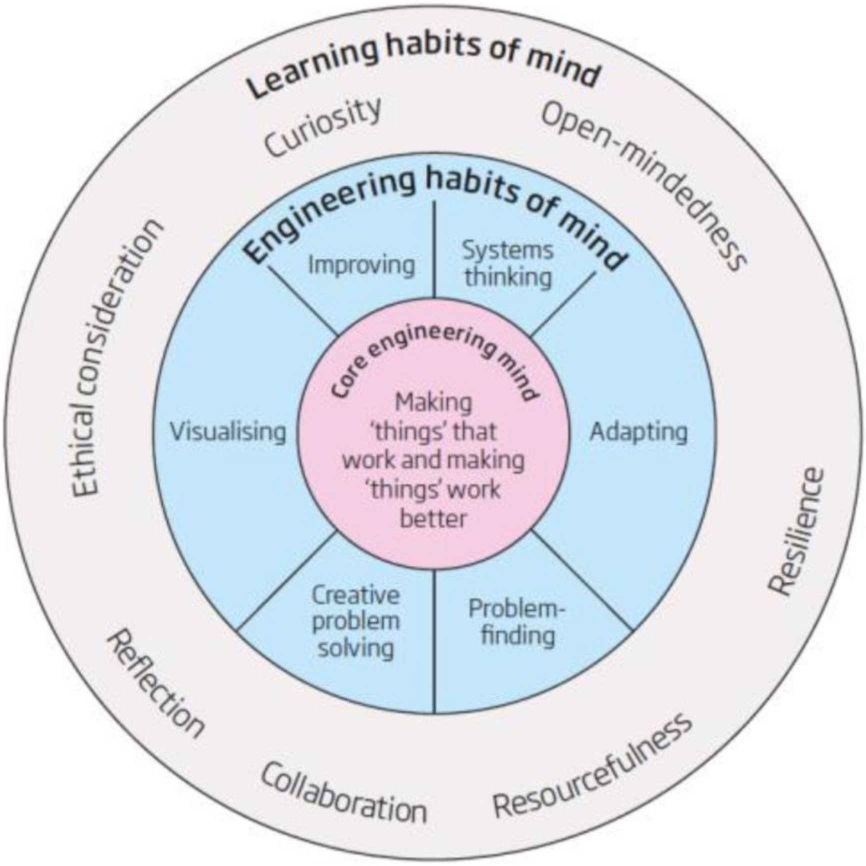

Figure 3 CRL's Engineering Habits of Mind (Lucas & Hanson, 2014, p. 6)

There is debate on how these skills can be learned at a general level and how they can be applied in a more specific way in D&T. McCormick (1997) problematizes the teaching of design problem-solving as a general skill and argues that the context will determine whether a problem is solved successfully depending on how much context-specific knowledge a person has in the domain where the problem presents itself. Additionally, McCormick (1997) states that while design or problem-solving are often taught as a ritualistic, step-by-step process or an iterative cycle in D&T, when applied in real life, this is hardly ever the case whether they are applied by expert technologists or students themselves. The design process depends on the context or the problem that is being solved (McCormick, 1997). On the other hand, having more generic skills may be considered advantageous as they may remain relevant for longer given the high rate of change in the technology domain (De Vries & Tamir, 1997). Therefore, while initial instruction of D&T skills needs to be embedded in a specific context, students then need to develop these skills at a more generic level by performing a conceptual leap. It is at this point that such skills start to carry more value than domain-specific knowledge (McLaren, 2012).

2.6 A curriculum for technology education

The curriculum plays a big role in how views of technology are shaped in students' minds (De Vries, 2016). A healthy way of conceptualizing technology stems from recognizing technology as artifacts, knowledge, processes and volition (Mitcham, 1994; De Vries, 2016). A curriculum for technology education can therefore be assessed by identifying opportunities for these conceptualizations to be made.

Another measure of quality of a curriculum for technology education is to look at the references at the end of the document – literature from the field of philosophy of technology should feature heavily in the list (De Vries, 2016).

A recognition that technological literacy is not merely acquired through a specialized school subject should also be present in a sound curriculum for technology education (De Vries, 2016). As often discussed, the field of technology borrows knowledge from other disciplines and this idea should be clearly conveyed to students even though it may not always be easy to do so (De Vries, 2016). A first step in doing this would be to attempt a STEM approach where science, technology, engineering and mathematics are integrated and students are presented with design challenges that genuinely require the use of all these disciplines and not challenges that can be solved through trial and error or where the use of science and mathematics is seen as a deviation which detracts from the enjoyment of the activity (De Vries, 2016).

Another valuable source for informing curriculum content are the Standards for Technological and Engineering Literacy published by the International Technology and Engineering Educators Association (ITEEA, 2020). The eight core standards identified are (ITEEA, 2020, p. 7):

1. Nature and characteristics of technology and engineering
2. Core concepts of technology and engineering
3. Integration of knowledge, technologies, and practices
4. Impacts of technology
5. Influence of society on technological development
6. History of technology
7. Design in technology and engineering education
8. Applying, maintaining, and assessing technological products and systems

While analyzing curricula it is important to keep in mind that such documents are temporary and subject to change (De Vries, 2016).

2.6.1 The Maltese curriculum

The main curriculum document for Malta is the National Curriculum Framework for All 2012, also referred to as the 'NCF' (Ministry for Education and Employment, 2012). This document is a high-level document which sets out a general vision for education in Malta (Ministry for Education and Employment, 2012). One of its aims was to set up a Learning Outcomes Framework (Ministry for Education and Employment, 2012).

In 2015, the Educators' Guide for Pedagogy and Assessment Using a Learning Outcomes Framework for Design and Technology, which shall hereafter be referred to as the LOF document, was published (Ministry for Education and Employment, 2015). This document is specific to the subject of D&T – it establishes subject learning outcomes at different levels of ability, gives recommendations with respect to the choice of pedagogy and establishes methods of assessment (Ministry for Education and Employment, 2015).

A third document making up the Maltese D&T curriculum is the SEC33 Syllabus for students sitting for the Design and Technology MATSEC examination in 2025 (MATSEC, 2022). This document is also specific to D&T but is more detailed than the LOF document – assessment criteria at the first three levels of the Malta Qualifications Framework are given for each learning outcome. It is important to note that while syllabus revisions are frequent, the 2025 version is the first syllabus following a learning outcomes format. Even though syllabi were meant to transition to the LOF format in 2019, the advent of the COVID-19 pandemic pushed the release of these syllabi to 2022 for implementation into schools in the scholastic year 2022/2023.

3 Methodology

3.1 The semi-structured interview

The semi-structured interview tool was deemed to be the most appropriate research method for gaining insight into what the most relevant values and skills in the D&T field are. To have perspectives from different sectors, interviewees were recruited from academia, industry and the education sector. The academics were recruited from the Faculty for the Built Environment (FfBE) and the Faculty of Engineering (FoE) within the University of Malta. The industry professionals have different backgrounds – one is a mechanical engineer working in industry while the other is an architect and civil engineer running their own firm. From the education sector, the Education Officer (EO) for public schools and a Head of Department (HoD) from Church schools were recruited. Therefore, while all interviewees are somehow related to the field of D&T, they are also from diverse backgrounds. This was intended to give a rich and realistic view for what skills and values are nowadays being considered most relevant. A total of 6 key experts were interviewed.

During semi-structured interviews participants can give in-depth (Dearnley, 2005; Baumbusch, 2010), unique (Krauss, et al., 2009) and vivid (Dearnley, 2005) answers. Moreover, semi-structured interviews are versatile and flexible (Dearnley, 2005; Turner, 2010; Kallio, Pietilä, Johnson, & Kangasniemi, 2016) – more, or less structure can be introduced in the interview depending on the type of research being carried out (Kelly, 2010). The option of changing the sequence of questions (Dearnley, 2005) and the possibility of interaction between the interviewer and interviewee (Whiting, 2008; Galletta, 2012; Cridland, Jones, Caputi, & Magee, 2015) and are also desirable aspects of semi-structured interviews. The latter feature makes it possible for the interviewer to formulate follow-up questions as the participants give their replies (Hardon, Hodgkin, & Fresle, 2004; Rubin & Rubin, 2005; Polit & Beck, 2010). During semi-structured interviews, it is also possible for the interviewees to express their own, unique views (Cohen & Crabtree, 2006; Krauss, et al., 2009). Although it is almost intuitive that some prior knowledge of the research area would be needed to conduct a semi-structured interview, several authors confirm it (Wengraf, 2001; Cohen & Crabtree, 2006; Kelly, 2010; Turner, 2010).

Kallio, Pietilä, Johnson and Kangasniemi (2016) identified five phases in developing a semi-structured interview:

1. Identifying the prerequisites for using semi-structured interviews
2. Retrieving and using previous knowledge
3. Formulating the preliminary semi-structured interview guide
4. Pilot testing the interview guide
5. Presenting the complete semi-structured interview guide

These will be discussed in some more detail in the upcoming sections.

3.1.1 Identifying the prerequisites for using semi-structured interviews

As briefly mentioned in section 3.1, the researcher needs to have some previous knowledge pertaining to the research area or the phenomenon being investigated prior to conducting interviews (Turner, 2010).

Another prerequisite is to ensure that semi-structured interviews are well suited for obtaining the type of information required to answer the research questions being asked. Semi-structured interviews provide insight into people's perceptions and opinions about complex issues (Barriball & While, 1994). They are also suitable when participants are not highly familiar with the subject being discussed or when they deal with matters that interviewees are unaccustomed to discussing, these may include discussing personal values, plans and principles (Åstedt-Kurki & Heikkinen, 1994). In the case of this dissertation, interviewees were asked questions about skills and values which although they might call upon and use unknowingly and implicitly daily, they may not be accustomed to talk about. This made the semi-structured interview a suitable tool.

Semi-structured interviews allow researchers to concentrate on matters that are important to the participant, and they make it possible for individual insights to be voiced (Cridland, Jones, Caputi, & Magee, 2015).

3.1.2 Retrieving and using previous knowledge

Any previous knowledge on the research area needs to be critically appraised prior to carrying out a semi-structured interview related to the field (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). One way of doing this is through conducting a literature review (Barriball & While, 1994; Krauss, et al., 2009). For research areas where an extensive literature review is not possible, empirical knowledge may be used to supplement. Such knowledge may be available through field experts (Krauss, et al., 2009; Rabionet, 2011). In the case of this dissertation, it was possible to carry out a literature review.

3.1.3 Formulating the preliminary semi-structured interview guide

Semi-structured interviews are directed by the interview guide which is a list of questions (Whiting, 2008; Krauss, et al., 2009), that while providing structure to the interview, does not impose too rigid a framework (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). The aim of the interview guide is to gather comparable information that is relevant to the research area from each interviewee (Holloway & Wheeler, 2010) and help communicate the research area to interviewees such that talking points may be related to it

(Åstedt-Kurki & Heikkinen, 1994; Gill, Stewart, Treasure, & Chadwick, 2008; Krauss, et al., 2009; Cridland, Jones, Caputi, & Magee, 2015). A high-quality interview guide will facilitate conducting the interview and be reflected in the analysis of collected data (Barriball & While, 1994; Krauss, et al., 2009; Rabionet, 2011; Cridland, Jones, Caputi, & Magee, 2015)

The marks of quality for questions making up the interview guide have been described by various authors. These include questions that provide the richest possible data (Turner, 2010), and questions that are participant oriented (Barriball & While, 1994), not leading (Kallio, Pietilä, Johnson, & Kangasniemi, 2016), clearly worded (Åstedt-Kurki & Heikkinen, 1994), single-faceted (Cridland, Jones, Caputi, & Magee, 2015; Baumbusch, 2010) and open-ended (Dearnley, 2005; Whiting, 2008; Krauss, et al., 2009; Turner, 2010; Chenail, 2011). If questions having the above attributes are successfully incorporated in the interview guide, the resulting answers should be spontaneous (Kallio, Pietilä, Johnson, & Kangasniemi, 2016) and reflect interviewees' personal feelings (Whiting, 2008) and stories (Rabionet, 2011). Such conditions make it possible for new concepts to emerge (Dearnley, 2005; Krauss, et al., 2009).

Participants are required to answer predefined questions on main themes in the research as well as predefined and spontaneous follow-up questions (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Questions relating to the main theme are meant to help the interviewees to "speak freely about their perceptions and experiences" (Kallio, Pietilä, Johnson, & Kangasniemi, 2016, p. 2960). Predefined follow-up questions guide the participant to understand exactly the theme being discussed thus enabling optimal collection of information (Turner, 2010) and giving direction to the interview (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Spontaneous follow-up questions allow for expanding on salient topics which are deemed important (Kallio, Pietilä, Johnson, & Kangasniemi, 2016) thus allowing new thoughts to surface (Dearnley, 2005; Krauss, et al., 2009).

3.1.4 Pilot testing the interview guide

Pilot testing the interview guide is good practice when conducting semi-structured interviews. Through pilot testing, the researcher can discover any flaws in the interview guide such as insufficient questioning that will not give enough information to answer the overarching research questions or questions that may bring about answers that are not relevant to the research (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Another important aspect that is revealed through pilot testing is any potential ethical issues related to the questions being asked (Chenail, 2011). There are three main ways in which pilot testing can be carried out (Kallio, Pietilä, Johnson, & Kangasniemi, 2016), these will be discussed in the following paragraphs.

When the group of researchers in the research team reviews the interview guide, internal testing is said to have been done (Barriball & While, 1994; Chenail, 2011). The advantages of conducting this kind of pilot test include improving the wording of questions to improve clarity (Kallio, Pietilä, Johnson, & Kangasniemi, 2016), eliminating leading questions (Barriball & While, 1994) and highlighting researcher bias (Chenail, 2011). If the group of researchers engages in playing out the interview themselves, some light can also be shed on the way the questions may make the interviewees feel thus fostering more ethical and responsible research (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Internal testing may also be useful when other types of pilot testing are not possible for various reasons (Chenail, 2011).

The second type of pilot test that can be carried out is expert assessment. In this instance, the interview guide is discussed with experts who do not form part of the research team (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). The advantages of this type of pilot test are very similar to those described for internal testing, that is, shedding light on the relevance and coverage of the interview guide in relation to the research domain and improving wording and sequence of questions (Barriball & While, 1994).

The last and most common type of pilot test that can be carried out is field-testing wherein potential study participants are recruited and interviewed (Barriball & While, 1994; Krauss, et al., 2009; Turner, 2010). This type of pilot testing gives a real feel for how understandable (Barriball & While, 1994; Chenail, 2011) and salient (Krauss, et al., 2009; Chenail, 2011) interview questions are and whether they managed to invoke interviewees' insights and experiences (Barriball & While, 1994; Chenail, 2011). A field test may bring to light the need to re-order the sequence of questions or to ask questions in a different way (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Questions relating to the main themes can be improved while follow-up questions can be polished to make the interview guide more comprehensive in terms of answering the research questions (Krauss, et al., 2009). A more practical aspect of field testing is that it gives a better idea of how much time each interview will take (Chenail, 2011; Cridland, Jones, Caputi, & Magee, 2015). Limitations in the research design can also be identified through field testing (Turner, 2010; Chenail, 2011).

Pilot testing for this research was a hybrid between internal testing and expert assessment. The semi-structured interview guide was reviewed by the writer, dissertation supervisor and co-supervisor. While the supervisor and co-supervisor are both experts in the field, they contributed guidance to the researcher throughout the research, hence they are also part of the research team.

3.1.5 Presenting the complete semi-structured interview guide

The final phase in developing a semi-structured interview guide is to publish it as part of the study (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). This is done so that findings from the research can be evaluated in relation to prior knowledge, to illustrate, in a transparent manner, that the phases of development have been followed and that the objectives of the study can be addressed through the questions asked in the semi-structured interviews (Barriball & While, 1994). Such practice improves the study's rigorousness and trustworthiness. It also makes the study universal and makes it possible for the interview guide to be tested, used and developed further by other researchers (Krauss, et al., 2009; Kallio, Pietilä, Johnson, & Kangasniemi, 2016). See Appendix A – Semi-Structured Interview Guide.

3.1.6 Trustworthiness of semi-structured interviews – credibility, confirmability and dependability

Credibility, confirmability and dependability (Lincoln & Guba, 1985) contribute to the trustworthiness of qualitative research (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Each phase of developing the semi-structured interview guide described in the previous sections can be mapped to one of these metrics as shown in Figure 4.

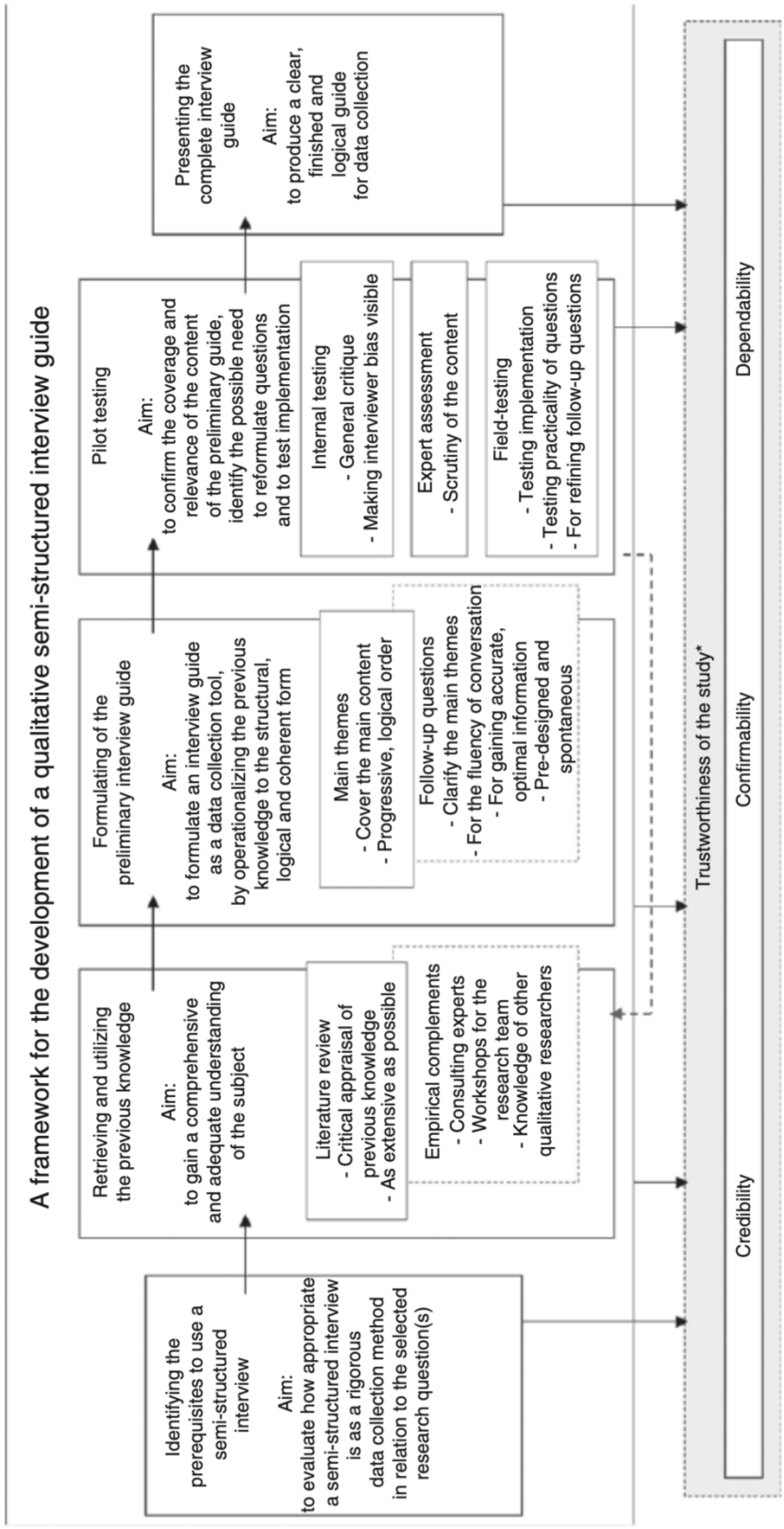

Figure 4 The phases of a semi-structured interview guide development based on the synthesis/review (*added based on the section of discussion) (Kallio, Pietilä, Johnson, & Kangasniemi, 2016, p. 2962)

Credibility refers to faithfully documenting the events being studied (Shenton, 2004). The first phase identified by Kallio, Pietilä, Johnson, & Kangasniemi (2016) is of particular relevance to credibility as it highlights the importance of choosing the correct research method. In the third phase, the importance of accurately communicating the main themes and interview questions were highlighted, these also contribute to the credibility as they make sure that interviewees understand and respond exactly in the way the interviewer intended (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Credibility is once again relevant in the fifth and final phase where the researcher publishes the interview guide as this shows fellow researchers what interview questions were posed to address the research question(s) (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). This means that other researchers may critically analyse results and conclude whether the study measured what was intended (Shenton, 2004).

Confirmability is the next metric that contributes towards the trustworthiness of research according to Lincoln and Guba (1985). They describe confirmability as referring to the researcher's objectivity (Lincoln & Guba, 1985). The second phase described by Kallio, Pietilä, Johnson, & Kangasniemi (2016), addresses confirmability as it seeks to reduce subjectivity by "using systematically collected literature-based and empirical previous knowledge" (p. 2963). Through pilot testing carried out in the fourth phase, subjectivity is reduced through discussing the interview guide and gathering critical feedback about it (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). The final phase also contributes by confirmability by disclosing the process of developing the interview guide through publishing and documenting the data collection process (Jensen, 2008).

The fifth phase is given importance once again when discussing dependability which refers to the possibility of repeating the study under the same conditions (Shenton, 2004). This would not be possible unless the interview guide is published and made available to other researchers (Kallio, Pietilä, Johnson, & Kangasniemi, 2016).

In this study, all three criteria are being met by publishing Appendix A – Semi-Structured Interview Guide, Appendix B – Interview Transcripts as well as disclosing the pilot testing of the semi-structured interview guide in section 3.1.4.

3.1.7 Difficulties associated with semi-structured interviews

As with any research method, difficulties are encountered when developing a semi-structured interview guide. The first that shall be discussed is the gathering of empirical information from experts mentioned in the second phase (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). While access to published knowledge may be facilitated through the online publishing of journals and institutional access to such journals, access to empirical information from experts may be dictated by the limited reach of the researcher's own professional network.

Another difficulty can be encountered in the third phase – spontaneous follow-up questions may be problematic for some ethics review boards as they would want to review all the questions in advance (Kvale, 2007). This may take away some of the flexibility allowed by semi-structured interviews and some of the interaction and authenticity resulting from answers gathered through semi-structured interviews. One way to anticipate as many of the follow-up questions as possible is to conduct as many field tests as possible with potential study participants. However, while this may uncover any ethical issues and formalize potential follow-up questions, it may be difficult and problematic to conduct in certain studies such as ones conducted over shorter time spans or where recruitment of participants is already difficult. In such situations, internal and expert pilot tests or a hybrid between the two may be better suited. Such was the case with this dissertation.

3.2 Thematic analysis

Thematic analysis is a qualitative, foundational, analytic method (Braun & Clarke, 2006). The skills acquired when conducting thematic analysis can be used across many other qualitative methods (Braun & Clarke, 2006). Thematic analysis aligns well with a variety of epistemological approaches and is thus considered a flexible research tool (Braun & Clarke, 2006). Another feature of thematic analysis that makes it flexible is that while it enjoys some theoretical freedom it can also yield rich, detailed and complex interpretation of data (Braun & Clarke, 2006). Braun and Clarke (2006) describe thematic analysis as “a method for identifying, analysing, and reporting patterns (themes) within data” (p. 6). Through thematic analysis, data is organized and can thus be understood (Boyatzis, 1998).

In thematic analysis, the researcher is not passively analysing data for patterns and themes to simply emerge. On the contrary, the researcher chooses patterns and themes which are relevant to their research and elaborates on them (Taylor & Ussher, 2001). To improve the validity of research and in view of the role the researcher plays in thematic analysis, it is important for the researcher to make an informed decision when choosing a theoretical framework and method to use (Braun & Clarke, 2006). Sometimes this needs to happen before the data collection phase, other times before the beginning of the analysis phase of the research (Braun & Clarke, 2006). This decision needs to then be disclosed to the reader when the researcher discusses results and infers meaning from data (Braun & Clarke, 2006). Thematic analysis is not bound to a particular theoretical framework like some other qualitative research methods are – a researcher employing thematic analysis can just as well be taking an essentialist or realist view, a critical realist view or a constructionist view – what's important is that the researcher makes this known since each position has assumptions associated with it (Braun & Clarke, 2006).

Selecting a theory to frame the research is not the only decision that needs to be made in thematic analysis. Choosing themes is a crucial part of thematic analysis. According to Braun and Clarke (2006) "A theme captures something important about the data in relation to the research question, and represents some level of *patterned* response or meaning within the data set" (p. 10). Since thematic analysis is a qualitative research method, there is no fixed rule about how many times a theme must appear in a data item to be considered a theme, there is not a rule which elaborates on how many of the data items need to have that theme mentioned within them either. Braun and Clarke (2006) call this the "prevalence" (p. 12) of a theme. As mentioned earlier, one of the advantages of thematic analysis is its flexibility – this flexibility comes through once again when determining the prevalence of a theme (Braun & Clarke, 2006). In this case, what is important is not the method used to establish how prevalent a theme is but applying that method consistently across the data set (Braun & Clarke, 2006). The selection of themes is subject to its relevance to the research question and up to the researcher themselves (Braun & Clarke, 2006).

An inductive or deductive approach may be used when determining themes (Braun & Clarke, 2006; Guest, MacQueen, & Namey, 2012). The inductive approach has also been called a 'bottom-up' (Frith & Gleeson, 2004) or data-driven approach (Braun & Clarke, 2006). In this approach, there would be robust ties between the data and the themes, and the identification of themes would not be motivated by the researcher's presumptions (Braun & Clarke, 2006). In this case, the researcher would ignore any themes identified by other researchers on the same topic (Braun & Clarke, 2006).

The deductive approach has also been called 'top down' (Boyatzis, 1998; Hayes, 1997) or theoretical or analyst-driven (Braun & Clarke, 2006) because it is guided by "the researcher's theoretical or analytic interest in the area" (Braun & Clarke, 2006, p. 12).

Thematic analysis can be done on two different levels – the semantic or the latent level. On a semantic level, the analyst does not look much further past the superficial meanings in the data and would tend to first give a description of the data by arranging, grouping, and giving a summary, and then try to interpret the data by generalizing the meanings of any patterns found and their consequences (Patton, 1990; Braun & Clarke, 2006). Research guided by an essentialist or realist epistemology assumes a straight-forward relationship between the individual, what they have experienced and the language they use to respond to questions asked to them (Braun & Clarke, 2006). The semantic type of analysis is therefore well-suited for this epistemological paradigm (Braun & Clarke, 2006).

On a latent level, however, the researcher delves deeper to uncover hidden meanings and identifies or examines "*underlying* ideas, assumptions, and conceptualizations – and ideologies – that are theorised as shaping or informing the semantic content of the data" (Braun & Clarke, 2006, p. 13). In this case, interpretation is required to extract themes themselves (Braun & Clarke, 2006). Research guided by a constructionist epistemology entertains the notion that meaning is constructed and passed down through social experiences (Burr, 1995). As such, researchers holding this perspective do not seek to understand the meanings inferred by singular individuals but rather what the specific socio-cultural context has imparted (Braun & Clarke, 2006).

3.2.1 A method for carrying out thematic analysis

In their 2006 paper, Braun and Clarke lay out a guide for doing thematic analysis. They divide it into 6 phases and give detail about each phase.

3.2.1.1 Phase 1 – Familiarizing oneself with the data

The first phase is familiarizing oneself with the data. For data that is in audio or video format, transcribing may be required first. Transcribing can serve to familiarize oneself with the data (Braun & Clarke, 2006).

The authors recommend that in this phase, the researcher reads the data repeatedly and does so in an active way to start probing for meanings and identifying patterns (Braun & Clarke, 2006). In doing so, the researcher is encouraged to annotate the data and start identifying potential codes for use in later stage (Braun & Clarke, 2006).

Since thematic analysis, like many other qualitative research methods, requires a high degree of familiarization with the data, which often comes from reading and re-reading, it is more suited to smaller sample sizes such as interview transcripts rather than data collected, for example, from questionnaires (Braun & Clarke, 2006).

3.2.1.2 Phase 2 – Generating initial codes

The potential codes identified in the first phase are formulated into initial codes in this stage of the analysis. Codes are more specific than themes and "identify a feature of the data that appears interesting to the analyst" (Braun & Clarke, 2006, p. 18). Codes are the smallest fragments, extracted from a data item, that can be meaningfully analysed (Boyatzis, 1998). A segment from the data can be coded more than once under different codes (Braun & Clarke, 2006). When extracting codes, it is important not to strip away the context, as this can often impart meaning as well (Braun & Clarke, 2006). The researcher should not be discouraged by data items which appear to conflict with each other – any such accounts should be retained and discussed (Braun & Clarke, 2006). Repeating patterns, emerging from codes can then become themes (Braun & Clarke, 2006).

Coding can be done in several ways and using several aids – computer software for coding may be used and when coding manually several approaches using stationery may be used. This is usually left to the preference of the researcher (Braun & Clarke, 2006).

3.2.1.3 Phase 3 – Searching for themes

The next phase of thematic analysis is to start grouping codes into tentative themes. It is important to retain extracts from the data in support of the selected codes (Braun & Clarke, 2006). Finding a means to visualize the coded data is encouraged as this may help patterns emerge more easily (Braun & Clarke, 2006).

Some codes may become themes, others may become sub-themes while other still may appear as if they do not fit under any theme (Braun & Clarke, 2006). Grouping of codes into themes and sub-themes should bring out the relationship between themes and sub-themes (Braun & Clarke, 2006). Braun and Clarke (2006) encourage not to discard any codes at this point, as these may become relevant later, instead, any themes that may appear to not fit can be placed in a 'Miscellaneous' theme.

3.2.1.4 Phase 4 – Reviewing themes

As the title indicates, in this phase the themes are reviewed. At this point, the analyst will start to notice that some themes may be combined, others may need to be further split, while others may not make the final cut (Braun & Clarke, 2006). Braun and Clarke (2006) suggest using the criteria of internal homogeneity and external heterogeneity mentioned by Patton (1990) to guide this phase of the analysis. These criteria basically establish that there should be homogeneity within the themes themselves, that is, the individual data extracts should be coherent and fit together, and that there should be enough difference between themes to make them actual, distinct themes (Braun & Clarke, 2006).

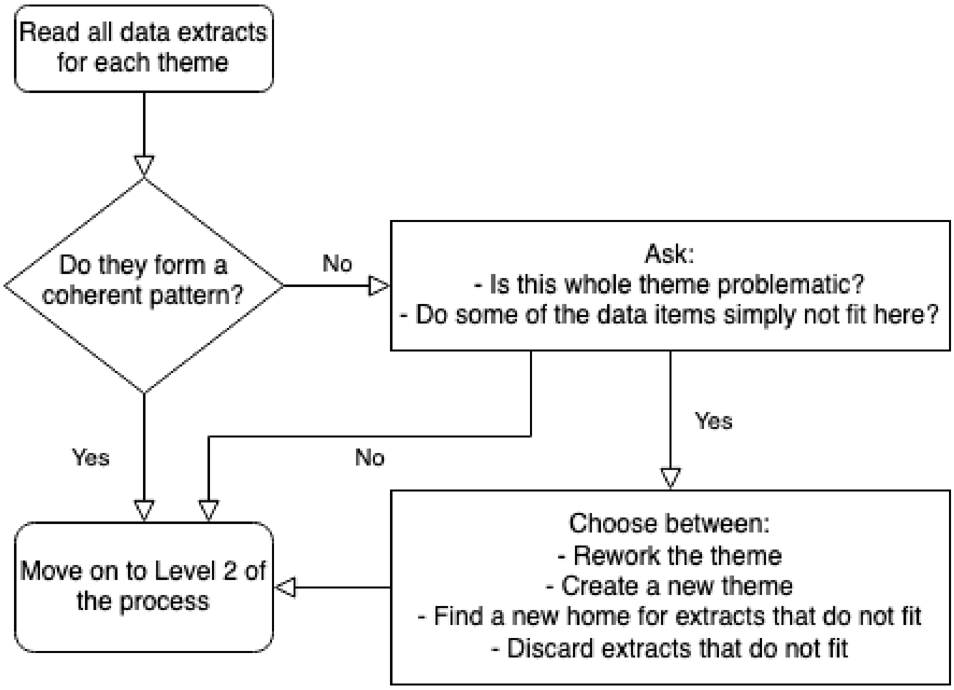

Figure 5 Flow chart representing the first level of the reviewing themes phase in thematic analysis (created with information from Braun & Clarke, 2006)

Reviewing themes should occur on two levels. The first level of refinement is summarized in the flow chart shown in Figure 5 and deals with the criterion of internal homogeneity within themes. Once level one is complete, the analysis can continue at the second level which deals with external heterogeneity. In this level, the legitimacy of each theme in relation to the entire data set is checked and the analyst ascertains that the themes generated are accurately representing all the meanings present in the data set and the relationships between themes (Braun & Clarke, 2006). Braun and Clarke (2006) encourage re-reading the data set to potentially code any extracts that may have been left out earlier into the newly created themes.

3.2.1.5 Phase 5 – Defining and naming themes

Braun and Clarke (2006) define this phase as "identifying the 'essence' of what each theme is about" (p. 22). This part of the research requires the analyst to interpret the themes by giving an analysis of each. The researcher needs to present what is interesting about the themes and why, describe how this theme fits into the 'bigger picture' that the data collected for the research portrays and how the themes identified address the research questions that the researcher set out to answer in the first place (Braun & Clarke, 2006).

3.2.1.6 Phase 6 – Producing the report

The final phase is to produce the report. The report must convince the reader that the analysis conducted, and its interpretation is legitimate (Braun & Clarke, 2006). To do so, arguments must be supported with enough evidence, in the form of data extracts, from the data set to support each theme (Braun & Clarke, 2006). Careful choice of extracts is warranted to adequately support any claims made – the extracts need to be immediately identifiable as belonging to a particular theme to bring out the relevance of said theme (Braun & Clarke, 2006).

3.2.2 Making valid analytic claims

To make valid analytic claims in thematic analysis, the researcher needs to ask themselves the following questions (Braun & Clarke, 2006, p. 24):

- What does this theme mean?
- What are the assumptions underpinning it?
- What are the implications of this theme?
- What conditions are likely to have given rise to it?
- Why do people talk about this thing in this particular way (as opposed to other ways)?
- What is the overall story the different themes reveal about the topic?

3.2.3 Pitfalls to avoid when doing thematic analysis

No research method is without its flaws and thematic analysis is no exception. Common pitfalls when conducting thematic analysis include failing to analyse the data at all (Braun & Clarke, 2006). This can occur if the researcher only focuses on grouping data extracts together without attempting to interpret what meaning these collections may have (Braun & Clarke, 2006). A related pitfall occurs when the researcher uses the data collection questions (for example, the interview questions) as the themes themselves – once again, no real analysis would have been conducted in this case (Braun & Clarke, 2006).

Another pitfall results from not adhering to Patton's (1990) criteria of internal homogeneity and external heterogeneity within and between themes respectively. A superfluous analysis could result in themes that do not embody or represent either the entirety of the data set or a particular aspect of the data set (Braun & Clarke, 2006). In some instances, it may also be the case that suitable support for the identified themes, through data extracts, is not provided and thus the analysis appears weak and themes unjustified (Braun & Clarke, 2006).

There may also be incongruence between the data and the interpretations given by the researcher (Braun & Clarke, 2006). The researcher must remain open to the possibility that other interpretations of the data, especially ones that are obvious, may be present and should consider them and make them explicit in the analysis (Braun & Clarke, 2006). Here, any contradictions between data items must be discussed (Braun & Clarke, 2006).

Another pitfall may result if the analytic claims made by the researcher do not match the epistemological approach taken (Braun & Clarke, 2006).

4 Results and analysis

Once the interviews were completed, they were transcribed and analysed such that common features of new technologies in D&T and the skill set and values needed to harness them identified by the participants were extracted. Coding and the identification of themes was achieved by means of thematic analysis (Braun & Clarke, 2006). The methodology described by Braun and Clarke (2006) was followed.

An inductive approach (Braun & Clarke, 2006; Guest, MacQueen, & Namey, 2012). was taken to determine themes from the interview transcripts. A conscious effort was made to not repeat common features of new technologies and skills and values needed to harness them identified in literature.

The thematic analysis carried out for this research was done on a semantic level. The data was first arranged and grouped, and some summaries can be read in the sections that follow. Patterns were then sought so that themes, their meanings and patterns could be identified (Patton, 1990; Braun & Clarke, 2006). It was assumed that interviewees answered questions directly, based on their experiences, therefore it can be said that the research was guided by an essentialist or realist epistemology (Braun & Clarke, 2006).

As part of the first phase of thematic analysis identified by Braun and Clarke (2006), interviews were transcribed. Automatic transcription of text by means of Microsoft Word Online was used. While this was of great help, the accuracy of the resulting transcripts was rather low, therefore, the recordings of the interview were heard again, and transcripts amended to improve their accuracy. The transcripts were then read several times. While the transcripts were being read, annotations for possible codes were made.

Phase 2 of the thematic analysis began during a subsequent reading of the transcripts in which each code was inserted into a Microsoft Excel sheet and excerpts from the data from each interviewee corresponding to the code were copied in the cells corresponding to the rows assigned to the code. Some excerpts fit under more than one code. Care was taken to not strip away too much of the context for each excerpt and some excerpts could be found under various codes.

Once the coding process was complete, tentative groupings were created. As Braun and Clark (2006) suggest, some of the codes became themes or sub-themes and some codes did not seem to fit, relationships between themes and sub-themes became apparent as some aspects of certain codes appeared to fit under one theme while some others appeared to fit under another theme. In this phase of the analysis, a concept map with all the themes and relationships was generated using the free tool at https://app.diagrams.net/. The use of a word cloud was also attempted to visualize the data, however, the results yielded were unsatisfactory.

The fourth, fifth and sixth stages of the thematic analysis were somewhat done concurrently. Once the concept map was generated, writing of the results and analysis chapter began. While attempting to discuss each theme, the theme was also being reviewed and there were instances where some themes were combined, split or entirely removed. At the same time, each theme was checked for internal homogeneity and external heterogeneity (Patton, 1990) using the flow chart generated from information available in the paper by Braun and Clarke (2006) and shown in Figure 5. The names of themes were sometimes changed to more suitable ones as the interpretation was unfolding and a discussion of how each theme fits into the bigger picture was being carried out. While producing the report, data extracts were included to support each theme. Care was taken to avoid the pitfalls described in section 3.2.3.

Eight themes and respective sub-themes and codes were identified from the thematic analysis. These are:

1. Access and cost of technology
2. Knowing your basics
3. Technology and communities
4. Cross-curricular learning
5. Constructivism
6. Mindsets (ways of thinking)
7. Types of knowledge
8. The digital nature of new technologies

The final concept map for each of these themes is presented at the beginning of each section where each theme is discussed.

4.1 Access and cost of technology

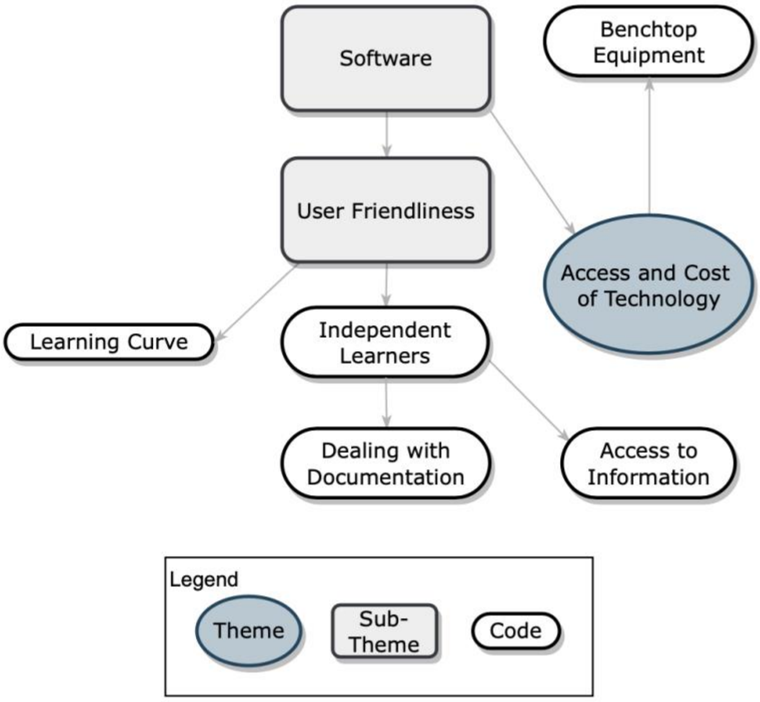

Figure 6 Concept map for ‘Access and cost of technology’ theme

One of the most prevalent phenomena about technologies that was highlighted by most interviewees was how accessible these are becoming. Reference was mostly made to accessibility in terms of cost. In this regard, the cost of some technologies has reduced significantly, while the entry point for some others remains somewhat high. The below excerpts from interviews attest to this.

> *"If anything, what's improved is the access to that. 23-24 years ago, we did programming. How did we do programming? We wrote it down on the paper because we didn't have access to PCs. We didn't have PCs other than in the computer lab at school and the personal computer era was just about starting. I speak about the mid 90s. So, we had to learn it in that way. Nowadays, with an Arduino or a Raspberry Pi, the world is*

the limit – quite literally the world is the limit. The sensors which you can have, the programming which you can do, the interface and then everything else at entry level prices." – Academic from FoE

"Are there certain technologies which are still overly expensive? Let's say that as I said, for example, with 3D printing, not so much. If you go to things like laser again, even just having an entry level with €400, you can start off with, same thing with the benchtop CNC machine. So, this type of benchtop equipment has improved greatly the accessibility of these type of instruments. On the other hand, if you want to go for a robot, then you're stepping up and over there, there is still, yes, quite a bit, because now we're not speaking about a few €100 anymore, but we speak about thousands of Euros... even in terms of, for example, open source software, simulation software and 3D printing software, CAM software, there's a much greater availability of those types of tools… Again, I'm speaking about robotics again, industrial robotics, if you get an entry-level like Lego, even that type, you still can do it with under €1000, and you can teach some of the principles of robotics over there as well with less than €1000 budget." – Academic from FoE

"...I don't think there is a financial issue, I don't think that is a barrier at this point. Affordability is very high for schools, for individuals, for the backyard inventor, they are accessible these items. Even for logistics and supply, I think there is no barrier for that as well. You can get access to anything nowadays, even locally." – D&T EO

"Well, the biggest barrier is the financing of it. I mean, I was lucky enough that the school was ready to invest, I understand that not all schools have the same budget or the same priorities that my school has, so the biggest issue with technologies is basically money. It's the funding of these technologies." – D&T HoD

Overall, the improved accessibility and reduced cost of technologies has had a positive reinforcing effect meaning that, the more accessible technologies become, the more people use them, and the more resources become available therefore making the technology even more accessible and reducing the cost even further.

"Because when you put it in many people's hands, that mass appeal, there's a lot more awareness of it and a lot more people who are experienced users of this kind of thing, so that's I think a common feature on a lot of new technologies coming right now. The accessibility of them." – Industry Professional with Mechanical Engineering Background

4.1.1 Benchtop equipment

Access in terms of the physical size of new machines was also mentioned with some interviewees mentioning that some technologies can now literally be placed on a desk in an office while some other technologies have benchtop versions.

"...this type of benchtop equipment has improved greatly the accessibility of these type of instruments." – Academic from FoE

"...we managed to pull off quite a sizeable pavilion with a desktop size CNC router. It was 90 by something, I don’t remember. It was meant to

be a prototyping machine that we kind of abused to be a full-blown CNC."

– Academic from FfBE

"3D printing, you know they used to be big industrial machines, now they're things that can fit on your desk and that a child can use." – Industry Professional with Mechanical Engineering Background

This last quotation not only points towards the miniaturization of equipment but also towards how easy to use some technologies have become. This is another form of accessibility that can sometimes be attributed to the user friendliness of software and its accessibility due to lower costs or free versions.

4.1.2 Software in terms of accessibility and cost

The aspect of accessibility and cost of software will be exclusively discussed in this section. The fact that software forms part of the digital identity of new technologies is discussed in a separate section under the 'Digital nature of new technologies' theme. Several aspects fall under this sub-theme: from the cost of software to its user friendliness and associated learning curve.

4.1.2.1 Cost of software

Some interviewees mentioned that software has become cheaper and, in some instances, even completely free to download, install and use.

"…even in terms of, for example, open-source software, simulation software and 3D printing software, CAM software, there's a much greater availability of those types of tools…" – Academic from FoE

4.1.2.2 User friendliness and learning curve

For the most part, interviewees mentioned how easy it has become to use software due to its improved user friendliness.

> *"Software you know, new software solutions, making it very easy to code, so there is broader appeal for people to use it." – Industry Professional with Mechanical Engineering Background*

> *"The way that you would prepare a CAD model for 3D printing now compared to then is absolutely the same, but the CAD tools have improved – more user friendly. The simulation tools and CAM tools which go with these machines have improved drastically. Before you needed to be an expert in order to have access to these. Nowadays. I'm not saying I'm not an expert, but it's a very simple thing. At the back of my office…" – Academic from FoE*

> *"CAD might be a high-end tool which after all most makers don't use to the full. Today we've got access to much cheaper software, maybe also that's easier to use. I mean, let's talk about some stuff like SketchUp. Let's talk about TinkerCAD. They're easier to use and maybe you don't need to know how to use CAD at the level that CAD allows you, but I think that would be enough, for example, for you." – D&T HoD*

> *"...when I was young, a software was not intuitive, you had to do everything yourself, maybe sometimes using DOS, and maybe sometimes*

being like almost a hacker, to actually use a package. Today, it's actually literally impossible to not make something work." – D&T EO

"...skills are quite simplified nowadays because it's different from trying to learn exactly how to hold a mechanical tool like a hand saw – you need to have a good position, and good posture, and good distance from your bench. So that one would have typically required a specific guidance or instruction. Nowadays, with digital skills... you need less of an instruction to do it. The software will be guiding you throughout, either with a wizard or else with some sort of some help or assistance within the software... You don't even need to be particularly skilled technically, or particularly skilled artistically, which before were more accentuated..." – D&T EO

The interviewees coming from industry, who highly value speed and efficiency, do not seem to have the time to dedicate to learning how to use new technologies. The more quickly a technology can be learnt the better. This is very often related to how user friendly the software accompanying that technology is.

"...you need to have time to learn, time to waste time learning, you know, and I think our generation isn't as fluent or let's say the younger generations with digital technology are much more, you know, efficient and fast than the older generations." – Industry Professional with Structural Engineering Background

"When you're doing a project, you also won't have enough time to learn a new technology from scratch. You are going to have to learn the

parts that are relevant to you and the rest will have to go along kind of. So, it's that prioritization, in the interest of time." – Industry Professional with Mechanical Engineering Background

One interviewee complained that since software has become so easy to use with learning curves that are much shallower, sometimes it ends up being misused, thus impoverishing design rather than enriching it. They compare some older software packages (Maya and 3Dmax) that were rather difficult to master, to a newer software, that is very easy to learn and free to use (Sketchup). In the interview, the interviewee claims that since the older packages were more difficult to use, students would follow a more manual design process – developed through sketches and physical models. This meant that students became more familiar with projects; their scale, massing, what type or form of materials could be used and other features. Now, with easy-to-use software, students are tending to skip the physical modelling and thus know less about their project and cannot develop the design to its full potential.

"…certain tools are actually detrimental for creative thinking and design thinking because a lot of times… they're easy to learn, so before it was like Maya and 3Dmax, very difficult to learn, the learning curve was very high… SketchUp doesn't allow you to do curves. So, then what happens is what is considered as instrumental knowledge, the knowledge of the tool, caps your design skills." – Academic from FfBE

4.1.3 Independent learning, documentation and access to information

Some of the interviewees talked about how, thanks to how intuitive devices have become, it has become easier to learn how to use technologies independently. One interviewee talked about the way users are now dealing with documentation and the access to information relating to technologies.

"...it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow. So, some people, even some teachers, would resist that a bit because they say listen, I'm not trained fully with the software, so their barrier is I'm not trained like I was with the particular hand tool for this, so they expect that training to be fully spelled and shown. Whereas the barrier is more at psychological one that people think that I have to have all the documentation in my hand to do this, whereas even if you see a 5-year-old today, if you give them a new device, they would need no paperwork, no explanation, just leave me alone, I will intuitively do this." – D&T EO

"...we're living in the information age and there is nothing you cannot find in any case of knowledge. I'm not saying that we don't need knowledge or knowledge is not important, but it is more accessible today... It's just also not delivered in the same way as before... if the information is made available like it was before, so you have to find that book, or find that file online, whatever, and you have to read it, there's still resistance to that approach, because I believe that nowadays, people tend to not want to have the full book and then go to do something. I believe information has become like an extension of our body. It is there, you call it, and you need it, and you look at it whenever you need. It's not like you have to fill the battery with knowledge all the time to start working." – D&T EO

In a similar manner to the interviewee above, another interviewee also made comments with regards to independent learning and access to information:

"If you want to learn something, it's there." – Academic from FoE

"I haven't gone to the library in years now. I find everything on the Internet." – Academic from FoE

4.2 Knowing your basics

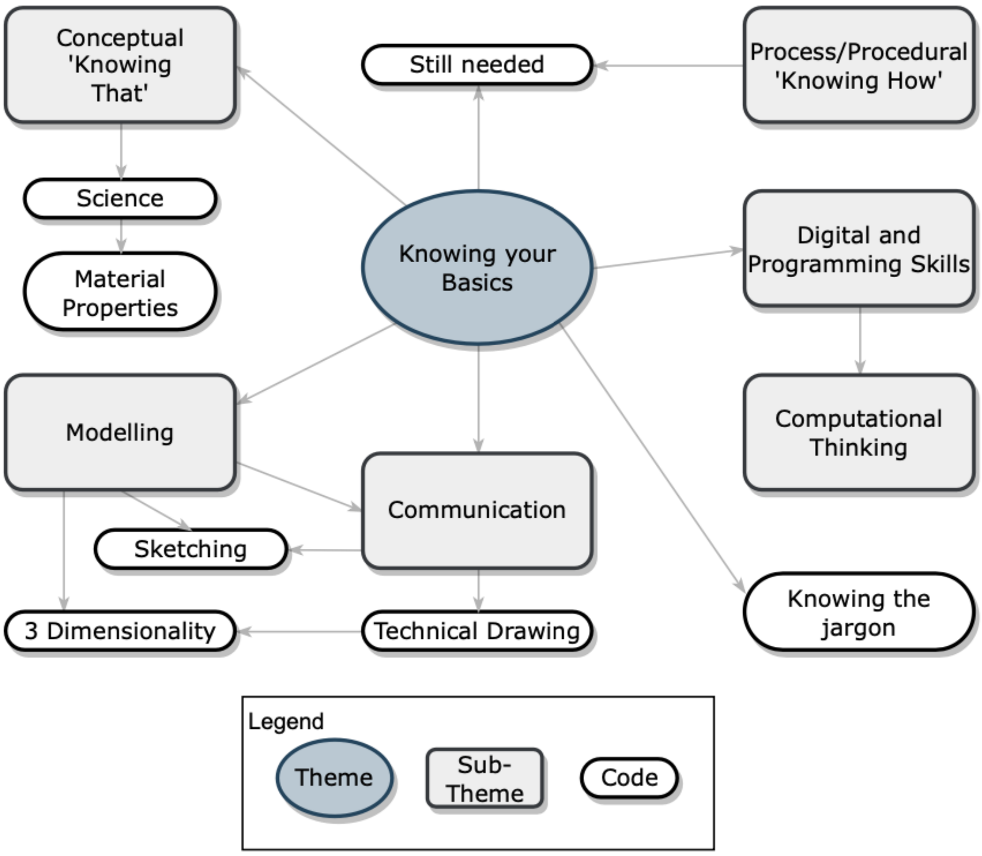

Figure 7 Concept map for 'Knowing your basics' theme

"...one of the fundamental priorities is to know your basics. So before ever learning any new technology, you need to know what you're

actually inputting into any new program that might be available." – Industry Professional with Structural Engineering Background

"...building a frame structure. It's always the same frame structure you're always gonna look for the nodes between the frame in any program. It's the same thing, you know, and we're always gonna implement the same building codes and the same standards within the program, so there's all that commonality. It's the same analysis if it's being done with the same code of practices..." – Industry Professional with Structural Engineering Background

One of the things that interviewees mentioned very often was the importance of knowing certain basics. Very often these so-called basics could very easily be traced back to the forms of knowledge mentioned by McCormick (1997) – that is, conceptual and procedural knowledge. In terms of conceptual knowledge, knowledge of science facts and material properties were mentioned specifically. Basic skills were also mentioned and interviewees from different fields mentioned different basic skills depending on their background. One interviewee in particular spoke extensively about instrumental knowledge and how, while this is important, it should not cap or limit creativity or the design process. Among the specific basic skills that were mentioned there were sketching, modelling and technical drawing which were grouped under communication and digital and programming skills.

4.2.1 Conceptual knowledge – 'knowing that'

Conceptual knowledge was not mentioned directly by the interviewees, rather, they mentioned heat transfer, physics and mathematics (which were grouped under 'science' for the purposes of the thematic analysis) and knowledge of material properties.

While conceptual knowledge is regarded as being important by the interviewees who mentioned it, there seems to be a mismatch in how to approach this type of knowledge. The biggest contrast arose between the two interviewees from industry – whereas the structural engineer places a lot of importance on knowing the basics first as can be seen from the two quotations in the previous section and the first two quotations below, the mechanical engineer does not put as much value in knowing the conceptual knowledge very well since they claim that this can easily be retrieved from books (see third quotation below).

> *"...basic physics would be the fundamental part because understanding that, I don't know, if I remove this, that's gonna fall… You know, the physics part of it is fundamental in that case." – Industry Professional with Structural Engineering Background*

> *"...from the mathematical and the physics side of it, that's where I would go, I would learn the science aspect…" – Industry Professional with Structural Engineering Background*

> *"If I went to everyone from my year of students and asked them, OK, what are the heat transfer equations? Myself, number one, I would not be able to tell you. But I know they exist... I think it would be more optimal*

that you show, to give a problem on how to use them, learn how to use them once or twice, but then you kind of put it at that. It's not like you have more complicated and complicated problems." – Industry Professional with Mechanical Engineering Background

This quotation, together with the one below both seem to support a perception that academics place a lot of importance on conceptual knowledge even though neither of the two academics interviewed made any claims that would support this view.

"...engineering course coordinators... at university level... insist that 'knowing that', the approach of knowing the foundational knowledge at first hand, like having the full book covered, before going into 'knowing how', is very important. Obviously, it is a higher level..." – D&T EO

On the contrary, the academic from the FfBE spoke extensively about "investigating material properties" in a manner that seemed to indicate that this would be done when the need arose during the design process:

"…investigating material properties so materials would do what they're meant to do. So opposite of I want it like this, so let's make it out of reinforced concrete or steel, it's like no, let's see what timber wants to do, you know, kind of working with the properties of materials… and then to a certain extent, buildings end up looking organic and curvilinear, but not because necessarily that was the intent, it's because that kind of emerged from the process." – Academic from FfBE

The same interviewee also agrees with McCormick (1997) on two of his claims about knowledge in technology – first, that conceptual and procedural knowledge 'feed off each other' indicating that there is a relationship between the two and second, that conceptual knowledge in technology is often a part of an active process, a process where the design knowledge 'grows'.

"...with every cycle... if you're doing material investigation and maybe bending something, now I know what material will do, but what will, let's say, the machine itself allow me to do? Now I know more about the material, more about machine. How do I marry one to the other? So, I think it kind of forms this circular loop. I would put them all under the umbrella of design knowledge, both of them. So, the design knowledge grows with every iteration and that's why I think design should be both sketching on paper and prototyping on working models. Kind of, it needs to come out. Then maybe comes, you know, digital modelling and evaluation. And then... it's tested. And then it's probably going to fail. Now we know, and then we go again. So, I think it's an iterative process, but they feed off each other." – Academic from FfBE

4.2.2 Procedural knowledge

Reference to procedural knowledge as being somewhat a basic form of knowledge that is required was made, even though it was not made in a very direct way. The EO for D&T mentioned that there is a perception among younger generations that just because they watched a YouTube video about how to do something, means that they know how to do it:

"...there is a culture nowadays that even if you saw a YouTube video, I know it. Which is a problem. And let alone if you get an expert in front of you, the teacher, and so you listen, you use this machine, like this, like this, like this. So, I'm not an expert, I'm a super expert because I not only saw the video, I had the teacher telling me this. So, the teacher has the responsibility to make students realize that there are many ways to fail, and that's important." – D&T EO

While watching someone carry out a task or operate tools may be a good start for learning how to use certain technologies, it does not make one an expert and skills (procedural knowledge) will be refined and improved the more one practices them. While many manual skills have been automated or have had their accuracy improved due to the digitization of certain technologies which were previously manual, the knowledge of procedures is still very relevant as evidenced by the below remarks:

"… most prototyping work, and even machine work, previously was manual, so you needed to have the manual skills to operate those machines... It doesn't mean that we've automated completely the fabrication, and it doesn't necessarily mean that you don't need to have the skills and knowledge to operate those machines… but the actual machining knowledge still needs to be there. You need to know what cutters need to be used. You need to know which feeds, the depth of cuts and everything. The software doesn't automate everything for you, so whilst the machines are controlled more digitally, you still need to have the

knowledge of the process then which supplements that." – Academic from FoE

With this change in the nature of new technologies, the EO for D&T emphasizes the importance of changing the focus of teaching from using a specific tool to approaching a new workflow.

"Let's put an example of a new device, OK? These are very dynamic, things change a lot, so you cannot say I want to learn, or I want to assess how well they know this machine. It takes it a bit on a higher level. You want to assess their ability to grasp new concepts, so it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow." – D&T EO

The procedural knowledge is therefore still needed and considered a basic requirement. However, due to the nature of new technologies, the procedural knowledge required to operate technologies is also changing. This is discussed further in the relevant section under the theme 'Types of Knowledge'.

4.2.3 Jargon

The philosopher of education Christopher Winch claimed that "Beginning to learn a subject involves beginning to use the language of the subject and this is primarily a practical ability as the grasp of concepts is, on this conception, a practical ability that is learned, is norm governed and can be appraised." (2013, p. 132). It can therefore be said that being socialized into a field requires one to know the language of that field and therefore the language or terminology associated with it can be considered a basic skill. The EO for D&T refers to this basic skill as follows:

"...now you're going to slice an object on a 3D printer. So, what's the burden? OK, you need to have a grasp of the jargon, sometimes if it's, let's say, you need to know what infill is. Someone has to give you those basics." – D&T EO

4.2.4 Modelling, sketching, 3 dimensionality and technical drawing

Modelling, sketching, 3 dimensionality and technical drawing were mentioned to different extents by different interviewees. The two academics interviewed both placed an emphasis on at least one of these aspects. The academic from the FoE spoke extensively about the importance of understanding objects in three dimensions and technical drawing and said that despite there being several software packages that are now able to produce drawings much more easily and quickly, the very basic still needs to be learned through technical drawing.

"...that underlying skill, the capability of perceiving an object, not just by seeing, but by thinking of the objects in three dimensions and actually finding a way of how to transmit that, in fact, I'm a big believer in technical drawing for example, and technical drawing is one of the skills which allows you to develop that thinking, we still teach technical drawing to our first years… Do we actually do technical drawing in real life and in industry? No, no one goes and gets a drawing board and stays drawing, we have a CAD system to do that. It speeds up everything. But the thought process which is required to understand that object in three dimensions over there is fundamental... For me that is still an essential skill, even though we have the CAD tools, the CAD software." – Academic from FoE

The academic from the FfBE spoke on a very similar streak, highlighting how hand sketching and developing physical models leads to a better understanding of several different aspects of a project:

"I think AutoCAD is really useful for production of drawings, but not for the design development… building a model and developing the project through sketches and physical models… you'll see you kind of work with the site, you understand the scale… You work with the physical model, your working model, you understand the curvature, you understand the materiality, you understand gravity – that's probably the most important aspect." – Academic from FfBE

"...digital tools like AutoCAD, it's really how you use them. So, if you're going to automate a process you can do by hand, I don't think that tools will give you much. So yes, I can draft by hand, and I can draft in AutoCAD. Obviously in AutoCAD it's easier because of the printing and editing and all that... But also, I think something is also lost, especially maybe when nowadays a lot of students remove sketching because this kind of connection between your thinking and your hand and the pen. Uhm, I don't think that smoothness in kind of when you're seeking ideas or trying to make your thinking come out on paper, I don't think mouse or AutoCAD is easy to capture that." – Academic from FfBE

"...cardboard models that you will chop and re-chop and take photos and rethink and look at the shadows and probably they won't even survive, and then you know kind of like sketching volumetrically. I think

those should be used more and I think their value will never disappear... So old tools and sketching, I don't think those would ever be lost." – Academic from FfBE

The structural engineer interviewed, who was also educated at the FfBE at the University of Malta, also gives importance to sketching as can be seen from the excerpt below. It appears that professionals from the Architecture and Civil/Structural Engineering side place more emphasis on sketching while those from the Engineering side place more emphasis on technical design. This is somewhat understandable considering the more artistic nature of the architecture and civil/structural engineering profession in relation to the purely engineering profession.

"...we can have elevations and sections within minutes nowadays, as opposed to how it used to happen with ACAD. I still believe in, not the old technologies, but the basics you know, like I can never say sketching needs to be phased out for new technologies because I still believe that sketching is fundamental for you to be good in a program, for example." – Industry Professional with Structural Engineering Background

Interestingly, both academics linked either 3 dimensionality and technical drawing or sketching and modelling to gaining a better understanding of how the design could be achieved with different materials. This shows that modelling is not just important to form and function in a design process but may also facilitate the selection of fabrication methods, materials or material forms to achieve the design. The below excerpts from the interviews held with the academic from the FoE and the one from the FfBE respectively, elaborate further on this:

"3 dimensionality. Perception of objects in three dimensions, right? I think that is one of the fundamental things... if we're going to go into fabrication, then you need to have that perception. You have to understand… The relationship of that object with other objects, the construction of that object, the features within that object, so that object is made up of various features that can be, obviously manufactured in different ways. But the fact that you can perceive that object in three dimensions is fundamental. That leaves the door then, to CAD which leaves the door to 3D printing, to laser, etc. So, for me, that underlying skill, the capability of perceiving an object, not just by seeing, but by thinking of the objects in three dimensions and actually finding a way of how to transmit that..." – Academic from FoE

"... cardboard models... the fact that if I'm making something from paper, I automatically know it's a single curvature, automatically know it can be done from a sheet material like glass, like metal like you know, like I automatically have that building into that." – Academic from FfBE]

Digital modelling was also mentioned and placed under this theme as something which is becoming a rather basic skill. It is seen as a worthwhile effort in the development of a design, however, something that should occur at a more advanced phase of the design process and not early on.

"…the design knowledge grows with every iteration and that's why I think design should be both sketching on paper and prototyping on

working models. Kind of, it needs to come out. Then maybe comes, you know, digital modelling and evaluation." – Academic from FfBE

"Sometimes people think that it's either sketching or working on a digital model on a computer. I experienced that myself as a designer where before I did only sketching, when I learned different software, I did not just do only digital designing, I started to merge my sketching back and forth with the digital modelling up to a point where sometimes you don't even catch a pencil while you're doing that, but it's still there, so one builds on another they take different starting points, but it's an added skill and an added tool in the way I see it. " – D&T EO

4.2.5 Communication

The ability to communicate is also seen as a basic skill by most interviewees.

"... knowledge of communications is very, very important, and to know what needs to be communicated and really understand the difficulties and the issues which are encountered in communications, etc. " – Academic from FoE

"So, for me, that underlying skill, the capability of perceiving an object, not just by seeing, but by thinking of the objects in three dimensions and actually finding a way of how to transmit that... For me it's still very important that people can communicate using drawings and understand drawings, see an image of an object and understand how that

object is going to look like in reality in three dimensions." – Academic from FoE

The mechanical engineer from industry said that internal communication within the company is a big part of their day-to-day operation hence one needs to be skilled in this area too. In some instances, this can also be automated through coding.

> *"...light coding and so on… allows you to automate a lot of different things in your process, your day-to-day process... Even for information sharing with different parts of the group..." – Industry Professional with Mechanical Engineering Background*

Another aspect of communication which was mentioned was communication of design ideas with clients.

> *"...other design programs which I feel are fundamental, like Photoshop, like SketchUp, which help us communicate better with the client and help us give a better visual to what we're trying to design or give back to the client. I would mention also Lumeon as a program which is a very good, animated program and it gives you like a very good, realistic, visual of what your project might look like..." – Industry Professional with Structural Engineering Background*

Communication has evolved over time – whereas sketches were the primary means of communication a few years back, computer-generated images from digital models and digital walkthroughs have now become the norm when communicating with clients. In a competitive market, the ability to generate these images from digital models and digital walkthroughs would be considered a basic skill that helps a professional or a business to remain relevant and attract clients.

> *"...before we used to just give a sketch to a client on how something would look, and now there's a walkthrough on how you feel in a building and what you see, you can see every single detail in 3D without actually building it nowadays." – Industry Professional with Structural Engineering Background*

4.2.6 Digital and programming skills and computational thinking

Due to the prevailing digital nature of new technologies, interviewees regarded digital and programming skills as being a basic. Some of the interviewees also connected this to computational thinking since they believe that understanding and being able to emulate how a computer 'thinks' forms the basis of many different things that can be done on a computer.

> *"…with AI and computer vision – any form of programming – the programming languages change or adapt. Even the simulation tools which we have available, the programming tools which we have available, the languages which we utilise, change, but at the end of the day, how you program doesn't change." – Academic from FoE*

The academic from the FfBE builds on the same argument. They claim that they first like to teach students how to create an algorithm for making a simple shape and then move on to using software (Grasshopper) only once they have achieved this.

"I ask students to really understand the geometric logic of something they are developing, so once they fully understand, and we literally develop geometric logic as a step-by-step algorithm, you know, I start with… I don't know like a Polygon ABC, midpoint, maybe you know, connect… So, I tell them, develop an algorithm to the point where I follow line by line and I can actually, you know, develop that. Once we have that then we can use Grasshopper, you know, because quite often they get tangled up into using Grasshopper as a modelling tool, which it is not. It's modelling of logic or processes. So, this is where I kind of always… My focus is as I said, not aesthetics, not evaluation, but the process, design process itself and logic behind it." – Academic from FfBE

The EO for D&T recognizes the importance of starting to develop these skills at an early age and says that even though programming is not the focus, students are introduced to a flowcharts programming approach.

"…microcontrollers which can be programmed visually, because in design and technology we don't focus a lot on coding. So, flowcharts programming approach to microcontrollers is our main focus, but they are allowed to use any other approach as well." – D&T EO

The engineer from industry highlights the importance of having some coding skills as this can help automate processes and improves efficiency.

"...light coding and so on, because it allows you to automate a lot of different things in your process, your day-to-day process. Something that would normally take you 3 hours of data input can now be done with

a few clicks, an app or something. Even for information sharing with different parts of the group... it shows how important software is to efficiencies as well I think and that is probably one of the big things that's lacking, we only do a very basic amount of it..." – Industry Professional with Mechanical Engineering Background

4.3 Technology and communities

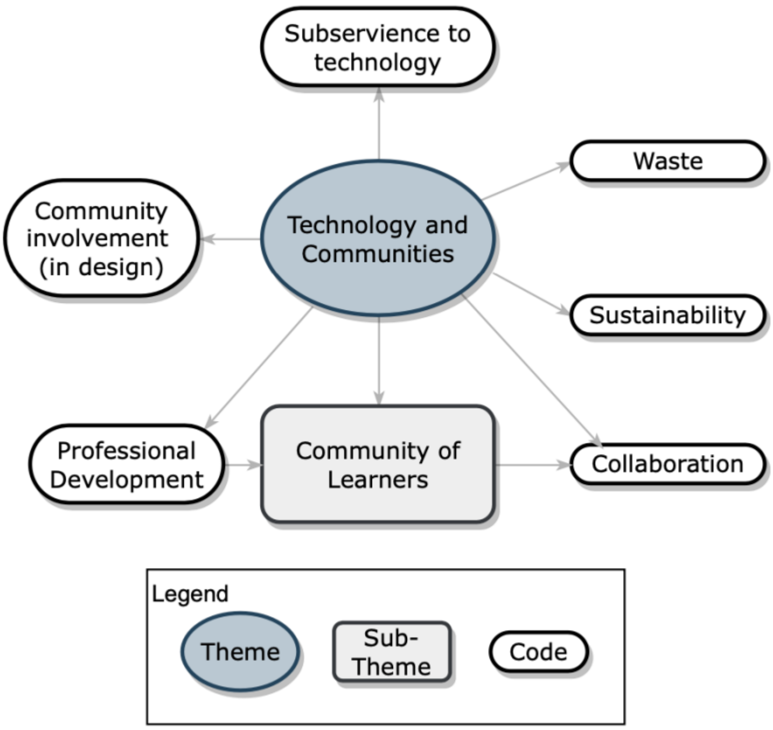

Figure 8 Concept map for 'Technology and communities' theme

Mitcham (1985) divides the philosophy of technology into two – the engineering philosophy of technology and the humanities philosophy of technology. The latter field seeks to understand the relationship that humans have with technology (Mitcham, 1985). This theme was inspired by this viewpoint.

4.3.1 Waste and sustainability

Four out of the six interviewees mentioned waste, sustainability or technologies related to sustainability during the interviews. These included the academic from the FfBE, the mechanical engineer from industry, and both interviewees from the education sector. With regards to waste, the academic mentioned the idea that waste is just something which we have not found a use for while the engineer spoke about sustainability in terms of product lifecycle.

> *"...constructing building with the current materials is failing us. The way we construct is failing us. You know with climate change, with overdevelopment… contemporary materials are failing us, and they're very CO2 intensive…" – Academic from FfBE*

> *"...waste is the most abundant resource, so waste is just lack of affordance. It's like it's something we didn't find a use for, so there isn't such a thing as waste – it's our lack of ability to find the use, to make it useful." – Academic from FfBE*

> *"...trying to learn as much as possible about the entire lifecycle whether it's related to manufacturing or sustainability…" – Industry Professional with Mechanical Engineering Background*

It is very encouraging to see that people from different fields are considering waste and sustainability as aspects which are our responsibility to tackle. Very often, engineering is blamed for environmental issues (Marshall, McClymont, & Joyce, 2007; Rossouw, Hacker, & De Vries, 2011) and those blaming technology for these issues expect technology to also resolve them (Rossouw, Hacker, & De Vries, 2011). The interviewees from the education sector seem to believe technologies can help in this regard and that the subject of D&T can illustrate such concepts at secondary level.

"...there is a very vast range of new technologies which students encounter every day. They are rather new and emergent, and they are the future – like embedded Internet in devices, like digital manufacturing is also one of these areas, alternative technology, alternative battery technology, alternative energy." – D&T EO

"So, they can see that, listen, technology is helping but in many different ways. Being time, being safety, being accuracy, and cost, obviously, because we're saving material because well before, for example, explaining to them, just to make it easier, for the teacher to deliver lessons we used to give a set material to each, so four sheets of plywood each student. Today, we don't do that anymore. When you do that, you have a lot of waste. Now we don't do that anymore because we are generating parts on the PC, we place all the parts next to each other, we nest all the pieces on one large A3 sheet without having any waste. So also, students can appreciate the cost benefits of using new technologies." – D&T HoD

4.3.2 Community involvement (in design)

The academic from the FfBE mentioned that there has been a shift in the world of architecture in recent years wherein architecture has become more dominated by participatory design and community involvement rather than star architects as was previously the case. The way materials are now being regarded is also different as there is a shift towards thinking more about what the material “wants to do”.

> *"So, let's say 20 years ago, architecture was dominated by star architects. Zaha Hadid, Frank Gehry, like Bilbao Museum, you know, like aesthetics, iconic building, like star architecture and iconic building, and now the switch is more kind of grassroots level, bottom up. So, things like working with communities, working with participatory design, investigating material properties so materials would do what they're meant to do." – Academic from FfBE*

This was very interesting since it means that buildings can be constructed in a manner that addresses the needs of the communities that they are being built for and thus is a perfect example of how communities are utilizing technology to fulfil their needs. It points directly to the critical aspect of the philosophy of technology (Mitcham, 1985; De Vries, 2005) and highlights the need for designers to have an understanding of psychology and sociology to design artefacts and buildings which are in tune with people’s feelings and the cultural setting (McLaren, 2012).

4.3.3 Subservience to technology

While the previous two sections talked about how technology can be used to improve lives, we must also be vigilant not to become subservient to technology. Technology should be regarded as a tool and used as such. We should not allow technologies to drive our decision-making process in a way that could impair our analytical thinking or limit our creativity.

“The user is in control. That's why I say it's a tool… there is an author who said that we are, sometimes it's a bit of a harsh word, but subservience to technology and it should be other way around.” – Academic from FfBE

4.3.4 Professional development, community of learners and collaboration

Many of the interviewees mentioned professional development at some point during the interviews. Professional development is very important to stay up to date with technologies and remain actively part of one’s professional community.

“I have to continuously remain updated and catch up with the latest technologies, the latest programming language, constantly to remain at the cutting edge in order to be teaching and training with the latest skills and knowledge.” – Academic from FoE

"...being willing to learn constantly, being open to new technologies and new ideas and having interest to say, maybe fine this program works for me, but maybe there's a better idea nowadays, which can help me be more efficient. Being open to that." – Industry Professional with Structural Engineering Background

“…most teachers tend to seek further training, so they don't actually show something wrongly because there is safety involved." – D&T EO

“…time for the teacher to train and be confident enough to use these tools there and then in class with the students... most of our

teachers... would be more than willing to learn how to use new tools..." – D&T HoD

Participation in professional development courses, conferences, seminars, etc., leads to the creation of a community of learners. Communities of learners therefore, do not just exist within formal educational institutions like schools, colleges and universities. Teachers who undergo professional development and further training are also indirectly promoting and modelling a behaviour and culture of lifelong learning for their students.

While the importance of independent learning has been discussed, learning in communities also has its benefits. Some learners may prefer this over independent learning. One interviewee in particular – the structural engineer from industry – specifically showed preference towards this:

"...having classes with people around you learning the same thing, even just practicing and giving simple exercises…" – Industry Professional with Structural Engineering Background

Some knowledge and skills may be more adequately gained in a community. For example, collaboration cannot be learned through independent learning as one must be in a community of some sort to collaborate with others. The academic from the FfBE emphasized how some amazing results can be achieved when there is collaboration and technology is used to its full potential.

"Where research excels abroad, in some hubs of research like ETH Zurich, is that they engage computer scientists to work with them and their

role would really be to go behind the scenes and take control…" – Academic from FfBE

"I think the exciting thing will be when eventually we get team up the craftsmen, the kind of the material knowledge, the traditional knowledge, from designers and architects and the computer scientists that will kind of unlock that barrier and allow also possibly even the traditional craftsman to engage and to transfer their knowledge into digital tools. I think digital tools have this amazing thing to allow collaboration, but there is this stumbling block of controlling them, not them controlling us." – Academic from FfBE

"...master masons... have knowledge of stones... There is kind of this tacit knowledge.... But then because of lack of technology, then they become limited to traditional tools and somehow, I think then, this kind of, know how, lack of knowledge, then there's a loss in a way. Then maybe architects know how to use certain technologies but don't have that tacit knowledge of the material... Through this process we all kind of learn and then the technology allows us that collaboration and that sharing of knowledge. It's kind of a platform." – Academic from FfBE

"I believe in teamwork you know. I think you need, as I said, crazy architects and then engineers to kind of shake... We need engineers to help us do all this. So, I think it's definitely a symbiosis." – Academic from FfBE

4.4 Cross-curricular learning

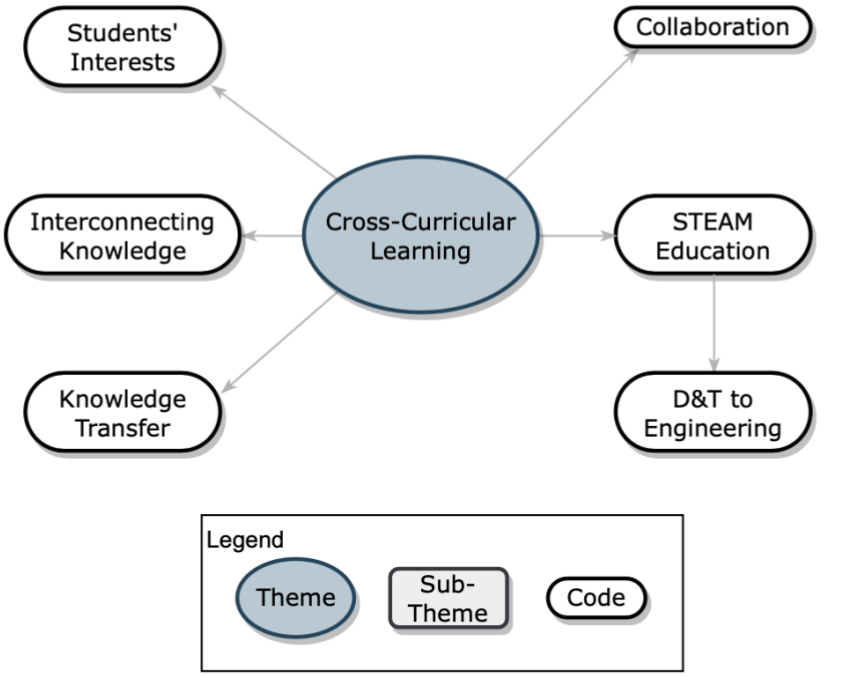

Figure 9 Concept map for 'Cross-curricular learning' theme

While it is not one of the largest themes, cross-curricular learning was touched upon in several ways. Technological knowledge in fact borrows and connects knowledge from various subjects (McCormick, 1997). Many authors have claimed that D&T provides opportunities for cross-curricular learning, that cross-curricular learning is necessary for successful teaching of D&T or have called D&T an interdisciplinary subject (Makiya & Rogers, 1993; Cross, 1998; Kimbell & Perry, 2001; Wilson & Harris, 2004). Interviewees spoke about the importance of being able to transfer and interconnect knowledge from other situations or disciplines such as art and sciences. Interconnecting knowledge can be used to make learning more appealing and to connect to students' interests. Collaboration, while already included under the 'technology and communities' theme was felt to be relevant to this theme as well, and in fact links the two themes together.

4.4.1 Knowledge transfer and interconnecting knowledge

Many of the interviewees mentioned that, many times, what was learned in one situation or with one technology or software can be applied in other situations or to newer technologies. Among the examples interviewees gave are programming, where learning one programming language can help with grasping other programming languages more easily. Another example was 3D printing – while the process of preparing a model for 3D printing has been simplified over time, most of the procedure is still the same and what was learned in the past still applies. Software packages are also easier to learn if a software that has a similar purpose is already known and the same codes of practice are being used – usually it's just a matter of changes in interface between different software packages. These phenomena are very important to point out as even though technologies are constantly changing, evolving or emerging, we can still identify some skills which remain relevant despite the changes. This helps students remain current and skills remain relevant.

> *"… with AI and computer vision – any form of programming – the programming languages change or adapt. Even the simulation tools which we have available, the programming tools which we have available, the languages which we utilise, change, but at the end of the day, how you program doesn't change." – Academic from FoE*

> *"So, I used to learn basic 23 or 24 years ago. The basic programming language. It doesn't exist any longer but what I learned over there in terms of setting up variables and loops, and if then statements, etc. What I learned there is portable throughout." – Academic from FoE*

"The way that you would prepare a CAD model for 3D printing now compared to then is absolutely the same, but the CAD tools have improved – more user friendly. The simulation tools and CAM tools which go with these machines have improved drastically. Before you needed to be an expert in order to have access to these. Nowadays. I'm not saying I'm not an expert, but it's a very simple thing. At the back of my office..."- Academic from FoE

"… once you learn the basics of 3D printing it's the process that changes and we have to learn the advantages and disadvantages of that process and all the nitty gritty of that process but at the end of the day, if you have a support structure for 3D printing, it's a support structure for 3D printing. If you're doing it for plastic parts or metallic parts…" – Academic from FoE

"...many of the design programs are fundamentally similar. It's just a question of interface at the end of the day, but once you learn one of them, I think it's much easier to learn the rest." – Industry Professional with Structural Engineering Background

"...building a frame structure. It's always the same frame structure you're always gonna look for the nodes between the frame in any program. It's the same thing, you know, and we're always gonna implement the same building codes and the same standards within the program, so there's all that commonality. It's the same analysis if it's being done with the same code of practices, so I think again it's the interface that

makes the difference mainly." – Industry Professional with Structural Engineering Background

Another idea that was included in this theme was that through, D&T, students can learn skills that can be transferred to other disciplines. One such skill is entrepreneurship.

> *"...other approaches like pitching design ideas, so it also enforces other skills which I think are more transferable in today's life because it's like a very, very entrepreneurial world, the word of technology nowadays, so it's an important skill which we're seeing." – D&T EO*

A final idea worth mentioning under this heading is that one type of knowledge can inform another type if the two are connected. This was expressed in the excerpt below and discussed further under the 'types of knowledge' theme.

> *"I believe that our students should be able to design and make because obviously they go hand in hand, so they'll be able to know the why and the how, because that's how obviously you get the best out of the material that you are, or your best out of your design, that you are building." – D&T HoD*

4.4.2 STEAM education and D&T to engineering

The Science, Technology, Engineering and Mathematics (STEM) movement has gained momentum steadily in the past years, it has also evolved to include Art (or Architecture to a lesser extent), making it the STEAM movement in more recent years. This gain in momentum can be attributed to the belief that these disciplines can contribute to a better economy (McLaren, 2012). The main idea of STEAM education is to incorporate science, technology, engineering, art and mathematics in a cross-curricular approach. D&T can be uniquely positioned at the intersection of these disciplines (Clark & Ernst, 2007). Interviewees mentioned many of the elements of STEAM as follows:

> *"It doesn't mean that because we encourage critical thinking, the critical aspect, the scientific and science thinking we don't encourage the arts, the open thinking or creativity. On the contrary, for me they are one and the same. We can't have one without the other. They're both very important to form the engineer of the future. The technologist of the future." – Academic from FoE*

> *"I think in secondary still, it's really allowing children, young adults right, to truly kind of express themselves and not ask them to kind of repeat what they see around them, but really allowing them, almost maybe mixing it with arts or with maths and then they make a video game… They make something you know; they wouldn't even know what they're doing. I mean I know my son is coding in Minecraft... if we teach, let's say, maths and physics, or allow knowledge from maths and physics to be applied in video games, carnival floats... I think then it's something fun." – Academic from FfBE*

> *"Generative art is such an easy to produce, it's so fun to kind of play out these beautiful images and video editing." – Academic from FfBE*

> *"...basic physics would be the fundamental part because understanding that, I don't know, if I remove this, that's gonna fall… You*

know, the physics part of it is fundamental in that case." – Industry Professional with Structural Engineering Background

"...from the mathematical and the physics side of it, that's where I would go, I would learn the science aspect…" – Industry Professional with Structural Engineering Background

D&T has the potential to provide an excellent platform and many opportunities for STEAM education which lead students into engineering and technology. As the academic from the FoE puts it:

"For me, design and technology is meant to lead towards the engineering. It's meant to prepare mentally, that engineer to start to think analytically, sequentially, in a well-ordered manner, scientifically, to a degree…" – Academic from FoE

4.4.3 Students' interests and collaboration

In D&T students are meant to encounter situations to which they must provide solutions. As discussed in previous sections, they need to bring together knowledge from different fields as well as gain new knowledge through the subject itself to solve these problems. The easiest way to motivate students to work on these projects is probably through appealing to their interests. Many of the interviewees mentioned this during the interviews.

"I think if they are really tapped into their passion, making music, and then the technology becomes not something you learn at school, but

something that you really kind of make it work for you." – Academic from FfBE

"...allowing them to really, really pursue something, and nothing is ridiculous, you know what I mean?" – Academic from FfBE

"My background at school as a secondary student wasn't too happy because obviously my love to materials and tools wasn't really appreciated in my time because obviously academics took over any other form of education basically." – D&T HoD

An interesting aspect that also came out is that student interest can also be piqued by linking to the real world and real life.

"Using digital tools... is a very easy way of how to entice students to develop a liking for the digital skills which are required because you're not just doing a computer programme which is a static program… No, you're running it on something which is real, and something which they can perceive and something which they can see." – Academic from FoE

Collaboration (which has also been discussed under the theme 'technology and communities') can also be an enticing aspect for students who like to work in groups. It also teaches important skills for working in inter-disciplinary teams later in their career. While seeking to learn new knowledge is encouraged, there may be instances where help from professionals or experts in other fields (e.g., computer scientists, craftsmen, fabricators, technicians, artisans, etc.) is solicited and this will require collaboration.

4.5 Constructivism

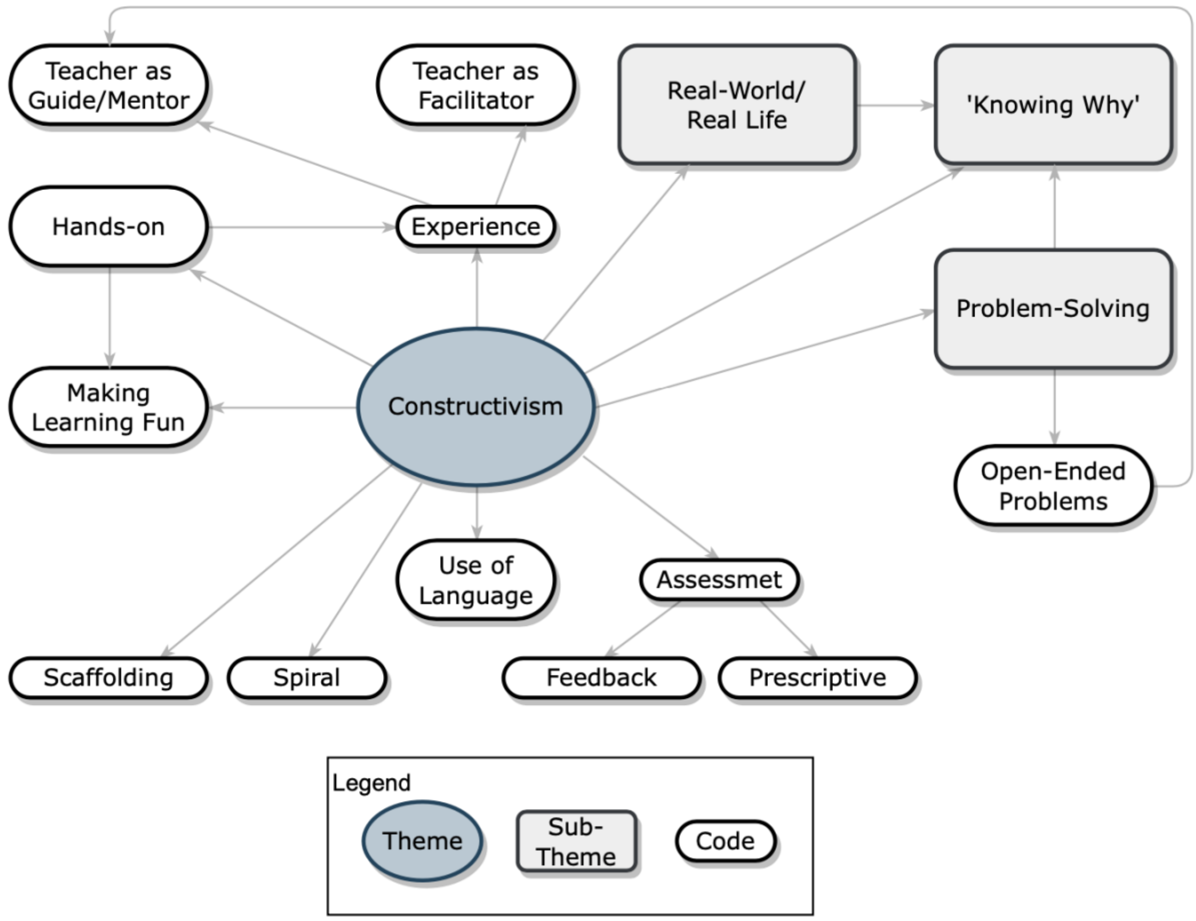

Figure 10 Concept map for 'Constructivism' theme

Many interviewees mentioned elements of constructivism, including the importance of experience and getting hands-on practice, making learning fun by appealing to students' interests, assigning authentic, real-world and real-life tasks which highlight the importance of 'why' students need to acquire certain knowledge, the role of the teacher, the skill of problem-solving, and some techniques which can be used in a constructivist environment such as scaffolding and teaching in a spiral. Interviewees also touched upon the social aspect of constructivism when they mentioned the use of language. The importance of feedback and how assessment can make curricula more prescriptive were also mentioned. These aspects were discussed in section 2.4 of the literature review. One of the interviewees made a very striking comment on the role of the teacher and the need for the teacher to understand that each learner is different due to their preferences and experiences (Han & Bhattacharya, 2001) and that therefore, success may look different for each individual student:

> *"What I believe a teacher should do is entice students. We cannot take all the students to one particular spot... and if you don't reach that particular point, you're a failure." – D&T HoD*

4.5.1 Experience, hands-on and making learning fun

Practical considerations gained from experience, or practical experience is one of the categories in Vincenti's (1990) engineering design knowledge (Ankiewicz, De Swardt, & De Vries, 2006). In the same framework, judgmental skills, which fall under the 'design instrumentalities' category of engineering design knowledge, are only learned through practical experience (Ankiewicz, De Swardt, & De Vries, 2006). The hands-on aspect was heavily emphasized and linked to experience by many of the interviewees.

> *"I'm the type of person who would only learn something after quite a good number of mistakes at trying to do it. But then I would know it, because during that process I would have gotten to know better why or how to do it properly and probably I would have searched couple of times what it is that I would have wanted to know." – D&T EO*

> *"Practice is practice. The more you practice, the better you get." – Industry Professional with Structural Engineering Background*

"...letting the student experience and go through the difficulties to learn the program itself." – Industry Professional with Structural Engineering Background

"From my experience we lacked the practical side of it. So, when I graduated, I had zero experience on site, zero experience in offices, I had worked in offices, but when you're a student you're just given… You know, not given the reality of it." – Industry Professional with Structural Engineering Background

"…we take the practical side for granted. Or rather, throughout the years, secondary, primary, even tertiary education, always lacked the practical side of it, unfortunately." – Industry Professional with Structural Engineering Background

The professional with a structural engineering background believes that hands-on activities build up experience which is then used to evaluate and question whether certain outcomes are reasonable.

"...if you input the wrong info, you're going to get the wrong answers out and the nice thing about having experience then in the field is noticing that the answers you are getting out are not making sense, so being able to question what you're getting back from a system, from a program." – Industry Professional with Structural Engineering Background

This is constructivism in action. In a constructivist paradigm, if the hands-on practice in school is regarded as building blocks which students use to then comprehend other problem situations and build their schema (McCormick, 1997), then one can easily understand why trying for oneself and practicing are so important.

One way in which McCormick (1997) suggests teaching how to solve problems in design is to have the teacher model how they would do this through either explicit instruction or the use of case studies. Pritchard and Woollard (Theory: the percepts of social constructivism and social learning theory, 2010) also recommend the use of examples between explanation and practice as a way of scaffolding learning in a constructivist setting. Interviewees seem to agree with this and mentioned these approaches specifically.

> *"...the practicing together, even going, maybe experiencing sites at a young age or experiencing, seeing someone doing the thing you're learning would help much more." – Industry Professional with Structural Engineering Background*

> *"I think one fundamental thing that we were missing in university is the practice side of everything... I think even in this case having a case study and just going through it together will teach students so much as opposed to learning the theory side of it. In my case, I would have preferred having a project and a lecturer telling me listen, we're going to solve this today together and that would have taught me 10 times more than just read the book and learn ACAD..." – Industry Professional with Structural Engineering Background*

> *"...letting the student experience and go through the difficulties to learn the program itself. So not spoon feeding too much. So, I understand the aspect of having our lecturers letting go and letting us learn on our*

own. However, I think there was a fundamental part which was missing, which was actually being there and experiencing at least an example together " – Industry Professional with Structural Engineering Background

"Sometimes you're the facilitator towards this different world. You're trying to show them that it is one of the best human achievements to be able to change something to achieve a particular result. And to do that you will not be showing the students, let's look how good I am, how good I am to do this. You're actually giving them exposure to a real-life success story, why not? Or case studies. " – D&T EO

In this last excerpt, the D&T EO assigns a very important role to the teacher as the facilitator of such experiences that should be built in such a way to lead students to the knowledge they need and the kind of experiences that will be fruitful to their learning.

"So, the teacher has to be the organizer of many little steps of wicked problems." – D&T EO

Other interviewees spoke about the role of the teacher as being a guide or a mentor and using questioning techniques to guide students in the right direction. This is very much in line with what Han and Bhattacharya (2001) recommend. These authors also recommend for teachers to assign specific tasks and to make learning outcomes specific and known (Han & Bhattacharya, 2001). Interviewees also hinted at these aspects.

"...pointing them in the direction of the right resources… It's more when you go off topic and off-track kind of thing. And setting deliverables

and their deadlines and so on..." – Industry Professional with Mechanical Engineering Background

"...when they're going off topic or off track, definitely off track, or when they're making a big mistake, you know or something, then they can come in and step in with real experience." – Industry Professional with Mechanical Engineering Background

"…on a higher level, the teacher is the person that communicates and guides and shows the path but doesn't plot the path. You tell them, "Listen, this is your goal. This is your objective. This is where you have to get to"." – Academic from FoE

"...guidance is also key when teaching this kind of material." – Industry Professional with Structural Engineering Background

"...asking them not to settle to what they know, not to repeat what's around and really pushing the analytical thinking, asking them questions to really understand what exactly they are doing. So, as I said, you're not making a specific object, but you're addressing a certain need or set of problems... in the way that really is suitable for what they're talking about." – Academic from FfBE

"...teachers should be just guides, they should help each student find their own goal, find their own targets and help them reach that goal... we have to always push our students to do their very best and help them, and guide them to reach their very best." – D&T HoD

The D&T EO very passionately mentioned that the teaching of D&T should be made up of experiences since this is what would last in time and in students' memories.

"...what I would actually give importance in the teaching aspect, is that the moment you are teaching them is an experience and then experience is the only thing worth to spend your time on actually. It's not worth studying by heart, something which, when you're finished with your assessment, will actually change." – D&T EO

On a similar note, one interviewee mentioned that one way of giving students lasting memories of a learning experience is to make learning fun:

"...there are specific teachers and specific people who are still up here just because of a comment they made or just because that particular lesson was fun and was interesting to listen to..." – Industry Professional with Structural Engineering Background

4.5.2 Real-world/real-life, knowing why and problem-solving

Constructivism requires that learning occurs in real-world situations where knowledge is constructed by the learner (Han & Bhattacharya, 2001). This idea builds on the previous notion that learning should consist of hands-on experiences.

"3D printing ... someone who's never used the technology, tell them your problem isn't just to learn what 3D printing is and print something and whatever, your problem is, I have this design and I want to optimize it for 3D printing. How am I going to do it? So having that objective helps you learn a lot more about the technology than if you just show them on a 3D

printer, told them, here's how you slice it, whatever. So, it's a hands-on and giving a problem to solve related to the new technology, I think." – Industry Professional with Mechanical Engineering Background

"Using digital tools... is a very easy way of how to entice students to develop a liking for the digital skills which are required because you're not just doing a computer programme which is a static program… No, you're running it on something which is real, and something which they can perceive and something which they can see." – Academic from FoE

"...at the moment they think that there is one solution... in reality, real life problems are those problems. Very rarely is it the problem, which is the opposite one, the close, and where there's only one answer." – Academic from FoE

Furthermore, the interviewees mentioned how important it is for students to know why they are learning what they are learning. This is one of the principles of a constructivist learning theory (Pritchard & Woollard, Pedagogy: the rules, principles and theories that guide current practice, 2010).

"...if I stick to our level, so let's say middle and secondary school, it's mostly striking the balance between 'knowing that' and 'knowing how'. But students will ask the question, "why do I need to know that this is this?", and "why do I need to know how to do this and this?" So, it adds the third column which would be, knowing why maybe, because it's a big question. They feel "why am I learning this? How will I use this in my future?" – D&T EO

"If we are able to make our pupils understand... that there is the need for you to learn how to use this tool, then things will be much easier because if you see a reason for a particular lesson, for a particular skill that I need to learn, then obviously you'll embrace that and you'll learn it much easier." – D&T HoD

"I never teach students how to use a 3D printer. That's not my aim. I set up a project where they understand that 3D printing would be an ideal way to solve this problem. So should they need to use a 3D printer, there is when I start teaching how to use a 3D printer or what a 3D printer is. So, they have a general knowledge of what it is, but then I do not make students use a 3D printer. They need to feel the need to use the 3D printer, so then they'll obviously need to know how to use the software, so you know, having students identify the need and then accepting their questions and answering their question basically." – D&T HoD

"...first you give the problem and then you say OK, now if you want, I'm going to do a lecture where I explain what 3D printing is or a lecture on the basics of Python. Then they can decide. OK I need that because I've never done it before. Whereas if you just told them, I'm going to do a lesson on it, they say, why would I need this?" – Industry Professional with Mechanical Engineering Background

Problem-solving, as a skill, can incorporate all these aspects – problems from the real world can be assigned to students such that they might employ hands-on work and previous knowledge or experiences to solve them. In doing so, they gain further experience to be used in future situations as well. Interviewees elaborated on several aspects of problem-solving such as how to break problems down, how to find solutions and how to do research. One interviewee shared their idea that problem-solving does not need to be a rigid and very structured approach. Analytical and critical thinking was also deemed important for problem-solving (this is discussed further under the ‘Mindsets’ theme). Another interviewee mentioned that while they agree with a hands-on approach to problem-solving, it does not mean that one must take on the traditional hands-on approach of using hand tools, rather, they mean that a more intellectual approach should be taken. In literature, this is sometimes referred to as a “minds-on” approach (McCormick & Davidson, 1996, p. 232). The importance of knowledge was also emphasized by the same interviewee – they claimed that it would be dangerous to try to solve problems without having the required knowledge. Problem-solving is contingent upon knowledge in the field of the problem (Glaser, 1984 & 1992; McCormick, 1997).

"We were always taught a number of problem-solving approaches… they teach you how to address a problem, how to break it down, how to look at alternative solutions, how to do research and so on. So, I think more of that... A lot of these things have to be taught, in a sense, this methodology, but enforcing the notion that you need to sit down, write down through the effects on a piece of paper, write down every single aspect of it, that's a bit of a slow-going process, and I think it turns people away as well when they're trying to learn a new problem-solving technique.” – Industry Professional with Mechanical Engineering Background

"...you're given a problem, you're given a task, and you have to critically think how we're going to solve that problem." – Academic from FoE

"...but that is where it gets dangerous in people's perception. Most people, when you tell them hands on, they think that they're actually, I don't know, cutting metal, actually welding things, actually... No. It is what I am meaning is you'll give them a problem and they have to solve it. That aspect of hands on." – Academic from FoE

"Can you do the problem-solving without having the knowledge? It's dangerous." – Academic from FoE

When it comes to the types of problems that should be assigned to students as part of their training in problem-solving, interviewees agree that open-ended problems would be preferred. This is also supported by literature (Han & Bhattacharya, 2001). Many spoke about problems which do not have just one solution.

"...the problems need to be more generic. So, in industry you're going to face problems not only with your specific need, whether it's design or manufacturing or whatever, but you're going to face a lot of other problems that are more holistic." – Industry Professional with Mechanical Engineering Background

"...instead of going for closed ended problems, we start to go for open ended problems. So not problems that have one solution and if you don't get that solution, it's wrong... Open ended problems that do not have

one solution but many different solutions – you have to try to choose the best one, but it doesn't mean that because you didn't choose the best one it's the wrong answer. Dealing with that is still very, very challenging." – Academic from FoE

"...at the moment they think that there is one solution. Why? Well, because everything that we've been trained, if it's maths there is only one solution, if it's physics, it's one solution, if it's chemistry, it is one solution. If it is technical drawing, it is one solution. It is the solution which you find at the back of the textbook or in the teacher's training book. For students to be able to go beyond that and say, 'Ah, this is a problem' and in reality, real life problems are those problems. Very rarely is it the problem, which is the opposite one, the close, and where there's only one answer." – Academic from FoE

"...all that is in design and technology is mostly based on this concept of a wicked problem where they have to solve something..." – D&T EO

"...the user requires this switch in thinking. Digital architecture is really kind of, as I said, possibly giving up of a very specific solution and allowing multiple variables to play out. Like the ability of the tool, the materiality – the design process becomes all these capacities and constraints coming together. I think that would be a common feature maybe." – Academic from FfBE

According to the academic from the FoE, the role of the teacher in this instance should be that of a leader – in the sense that the teacher should guide students to remain focused when they are about to wander astray, remind students about the objectives they set out to achieve and prompt students to use one of the multiple approaches taught for achieve them while still allowing multiple solutions to play out. This is opposed to the role of instructor where the teacher would be dictating specific steps and idealizing one specific solution as being the correct one. The teacher should only be reminding students of their goals and encouraging them to think critically and explore options to decide whether their choices are in fact guiding them towards that goal. In a way, this links back to the role of the teacher as a guide discussed earlier.

"...the teacher becomes instrumental in leading because then the teacher leads, not instructs, because the second you instruct you have one solution. The second you say you have to do ABC. Nobody will do D or E or think about Z. The teacher has to lead, "listen, you need to achieve this". How? Think, be critical, explore." – Academic from FoE

4.5.3 Scaffolding and spiral curriculum

Two of the interviewees mentioned the importance of helping students to break down problems into smaller bits and have one step leading to another. In a constructivist pedagogy this is known as scaffolding. In a similar manner, one of the two interviewees also mentioned the spiral curriculum where skills are developed over time and can be re-visited at different points in the learning journey. The underlying feeling is that apart from helping with cognitive loads, re-visiting problems also allows students to remain motivated as they learn and achieve more.

"Just start from something small and then you build on that. You can't expect to give them a big problem and immediately, from day one, they're going to get there. Slowly, little by little, they need to be nurtured to be critical, to think." – Academic from FoE

"...you have to give them small experiences which scaffold one to the other, that show that yes, I made this, I managed. I actually designed this part. I actually implemented this part." – D&T EO

"...the teacher has to be the organizer of many little steps of wicked problems." – D&T EO

"It's a good thing that the subject is still a spiral one. So, you're not confined to tackle a chunk of skills or knowledge at one go, you can still live it as an experience… to give the sufficient skill a step at a time..." – D&T EO

4.5.4 Use of language

In many of the interviews, the interviewees problematized the use of the term 'new' when referring to 'new' technologies and see this as being relative. Using the terms 'new' and 'developing' may indicate that the technology is not ready to be used according to the industry professional with a mechanical engineering background. To encourage people to use them more, technologies need to be normalized and spoken about in a manner which indicates that they are available and within reach. Both industry professionals mentioned that technologies continue to evolve and mentioned specific examples such as injection moulding and ACAD which, while having been around for a long time, are still improved upon and updated.

"...when it comes to new technologies, we have to be very careful in the language we're using. You know, things like 'developing'… OK, every technology is developing. Even injection moulding is a developing technology, if you call one developing and one established, that's a problem. If you say 'infrastructure', things like that. These are problematic words, so we need to treat new technologies as technology and not like, you know, nice, new whatever. And, again, 3D printing but it applies to software, it applies to modelling, it applies to VR, it applies to AR. We need to stop sensationalizing them basically and just make them more normal and real." – Industry Professional with a Mechanical Engineering Background

"...mention them as a new technology always and say this is a new technology, it's a developing technology. But when you say 'developing' it kind of indicates that it's not ready to go yet. But in reality, it's a technology that is very viable for a lot of different things." – Industry Professional with a Mechanical Engineering Background

"...the concept of 'new' is very subjective. Let's say, what is perceived as new, I would say that every time that we use, CNC equipment or 3D printers or laser cutters – all that is in the digital manufacturing sphere, is generally taken as new, but again, some people would refer to an LED as something new despite being there from 60s and 70s." – D&T EO

"ACAD is like, it's a relatively old, let's say old, program. I wouldn't say it's a new technology, but it's an ever-growing technology." – Industry Professional with a Structural Engineering Background

"...when we talk about new technologies, obviously it's always relative, because obviously some new technologies that were available in the beginning of my teaching career are today maybe also obsolete. Talking about having projectors, having these tools that we used to teach, resources used to use, or other machinery like lathe for example, which were new at the time. Today, obviously, we have to move forward with integration of computers now moving also to the integration of Internet of Things." – D&T HoD

4.5.5 Assessment

Han and Bhattacharya (2001) claimed that nature of problems assigned to students in D&T, that is, ill-defined and open-ended, makes it difficult to assess learning in D&T. To further compound this problem, students may choose different methods to tackle problems (Han & Bhattacharya, 2001). The D&T EO spoke about the difficulties encountered while setting up assessment for D&T. While it may be easy to assess if a student knows how to use a specific machine, since technologies change rapidly, it would be more desirable to assess the higher-order thinking skills required in the process of operating that machine to solve a particular problem. Higher-order thinking skills are more difficult to assess since they cannot always be made explicit or written down. Additionally, there are pressures such as time and other rules imposed by the educational system which further complicate the situation. Nonetheless, D&T has managed to achieve the highest percentage of continuous assessment based on coursework among the academic-listed subjects for which Secondary Education Certificate (SEC) examinations are available.

> *"...in terms of assessment there are some barriers… Let's put an example of a new device, OK? These are very dynamic, things change a lot, so you cannot say I want to learn, or I want to assess how well they know this machine. It takes it a bit on a higher level. You want to assess their ability to grasp new concepts, so it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow." – D&T EO*

> *"...if it's a course which is assessed summatively, so your marks add up, you are bound by other rules. You are bound that by this time you have to finish this, and you have to put this in right now and right now I want to check this learning outcome." – D&T EO*

> *"...they will have 20% in year 9, 20% in year 10 and 10% in year 11. Building up a 50% assessment on coursework, which is the biggest percentage in all the academic listed subjects. So, with the new syllabus, we're going to see that what we already had achieved in design and technology, which is a 50% aspect of course, is now formalized, and it will be a continuous assessment for our students." – D&T EO*

The constraints imposed by the education system led to some degree of prescription in the D&T syllabus, which so far, is only being mitigated slightly.

> *"...the direction of our new syllabus; less prescriptive, so it's less about this knowledge. We want to have a better experience…" – D&T EO*

"...there is a good development in terms of a small reduction in the prescriptive knowledge." – D&T EO

When speaking about assessment, it is also important to mention feedback. Feedback should inform students about the areas that require improvement (Han & Bhattacharya, 2001). The industry professional with a structural engineering background had the following to say about feedback:

"...I think they let us go too much in the sense, calculations, we were left to do it alone therefore I used to finish a calculation, I would say, therefore, OK. But I would never have been 100% sure because no one ever really checked my work, you know. Unless it's an exam. So, I think guidance is also key when teaching this kind of material." – Industry Professional with a Structural Engineering Background

4.6 Mindsets (ways of thinking)

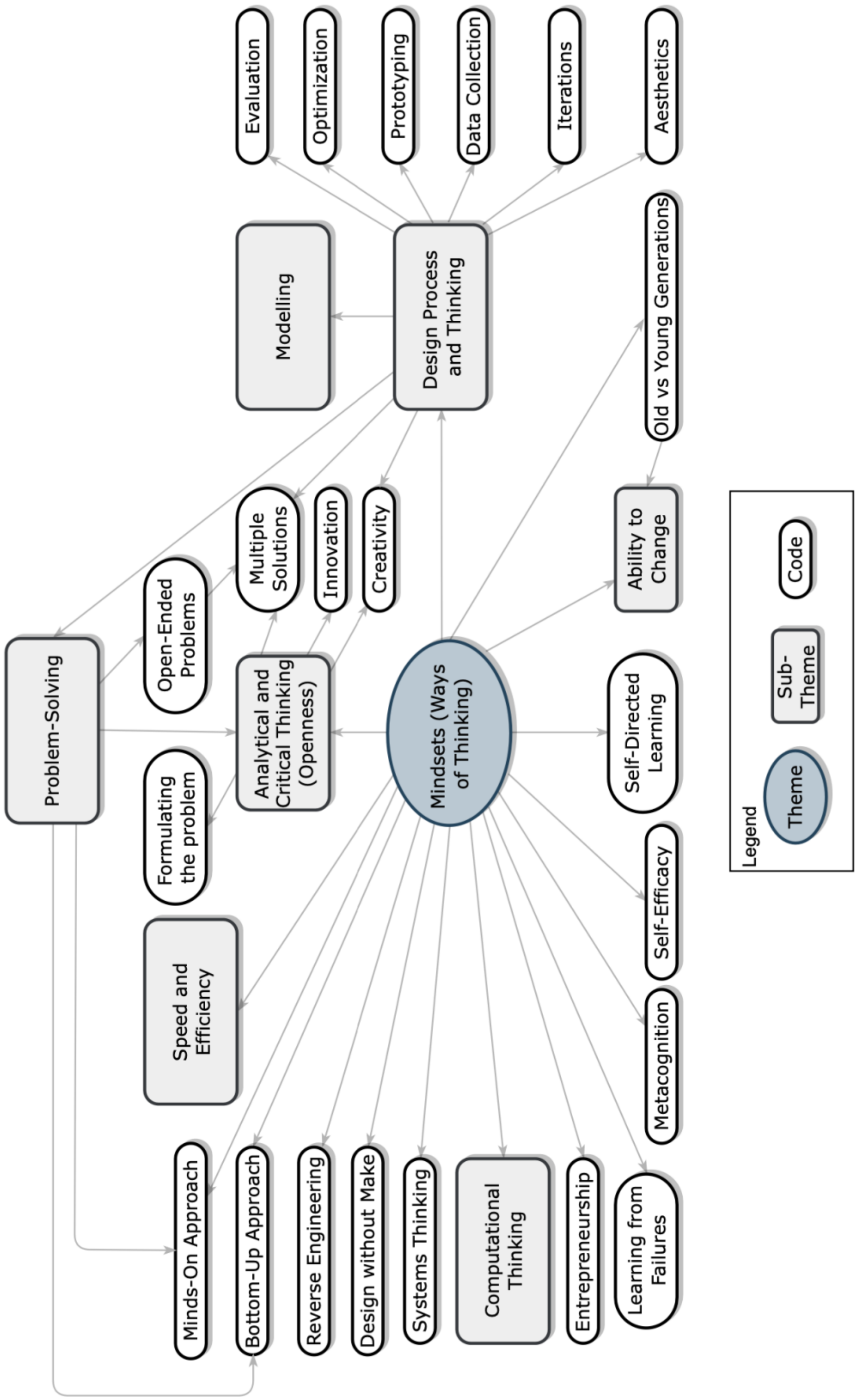

Figure 11 Concept map for 'Mindsets (ways of thinking)' theme

This theme incorporates some important aspects which interviewees spoke about. Some of these aspects can be qualified as mindsets, other as ways of thinking, others as approaches, and others as skills or values. They've been grouped all together due to the overlap between them and how sometimes one links to the other. Incidentally, one of the four groupings of skills identified as 21st century skills by Binkley, et al. (2012) is "Ways of Thinking" and includes "creativity and innovation", "critical thinking, problem solving and decision making" and "learning to learn, metacognition" (p. 18). It has also been claimed that in a knowledge economy "creativity, innovation and knowing how to learn carry greater value than knowledge itself" (McLaren, 2012, p. 8). Almost all these skills feature in this theme and are discussed hereunder together with other sub-themes and codes.

One of the biggest sub-themes under this theme is the design process or design thinking which forms the basis of the D&T curriculum. Some interviewees mentioned the design process specifically and spoke about it extensively, others mentioned individual parts of it as though emphasizing that part more than others.

Another sub-theme is problem-solving, which has also featured under the theme of constructivism. Problem-solving skills are required in a design process since the latter usually starts from a 'problem' that requires solving. Analytical and critical thinking, and considering multiple solutions for a given problem were highly valued by the interviewees as skills that lead to innovative and creative outcomes from the design process.

Computational thinking also falls under this theme and links it to the 'digital nature of new technologies' theme. Since new technologies seem to have a more digital nature, computational thinking will help one implement or execute their ideas using new technologies.

Several other codes were grouped under this theme; some of these are skills, others are approaches. For example, the ability to change is a skill that is linked to the value of lifelong learning. Other skills include self-directed learning, self-efficacy, metacognition, learning from failures, and entrepreneurship. Approaches include minds-on approach and bottom-up approach which are linked to problem-solving, reverse engineering, design without make, and systems thinking. These approaches can be used in D&T to aid in learning some of the important skills and values. While some approaches such as design without make and reverse engineering are very specific to D&T and there may not be other curricular opportunities to learn these, other approaches such as systems thinking and adopting a bottom-up approach may have been encountered by students in other disciplines such as environmental studies and computing respectively.

4.6.1 Design process and thinking

The design process overall was mentioned by the D&T EO who explained that with the latest iteration of the D&T syllabus, the approach to the design process is less rigid both in terms of number and sequence of steps and in terms of starting point. This is a shift in mindset in comparison to earlier versions of the syllabus where the design process consisted of a set number of steps which, although presented as a cycle, had to be followed sequentially.

> *"What we have also developed is a non-singular approach to the design process. If before we used to have a very structured, typical, design process with 10 stages, we broke that aspect completely and we're looking into the broad design process. So, it's explore, design, make, and evaluate which you can change non sequentially all the time and we could also be*

able to teach students how to design an object in different approaches. It's not always that you have to have the design brief and then you start research and then you start making and then test and you evaluate." – D&T EO

4.6.1.1 Creativity, formulating the problem and multiple solutions

Creativity was one of the aspects of the design process that featured in the interviews.

> *"One of the things that I really like is when there was the robot festival. You see the students who do these hands-on projects, with building and so on within their skill set. So obviously you're not expecting them to build the robot, but they try and solve problems creatively." – Industry Professional with Mechanical Engineering Background*

The way a problem is formulated or articulated can have a big impact on creativity as highlighted by the academic from the FfBE. An open way of formulating problems should be prioritized if repeating existing ideas is to be replaced by having multiple, creative solutions.

> *"I think necessity for analytical thinking and creative thinking so kind of openness...the crux of design, is formulating the problem that we are designing for, and I think that possibly, with current education, it's a lot of kind of repeating what we see, and I think new technologies allow us to start from scratch that's why analytical thinking is necessary... So, it's not the question of like "OK, we need to design, I don't know, vacuum cleaner". No. "We need to remove dust from this room". So, you start really*

rethinking the problem and then contemporary technologies will allow you to test it on the level of software analysis." – Academic from FfBE

"You really need to be open to everything and then creative thinking to say, "and what do I do?" Once I formulated this problem, how do I then follow it through?" – Academic from FfBE

"I think in secondary still, it's really allowing children, young adults right, to truly kind of express themselves and not ask them to kind of repeat what they see around them, but really allowing them, almost maybe mixing it with arts or with maths and then they make a video game… They make something you know; they wouldn't even know what they're doing. I mean I know my son is coding in Minecraft... if we teach, let's say, maths and physics, or allow knowledge from maths and physics to be applied in video games, carnival floats... I think then it's something fun." – Academic from FfBE

"We are not instructed to think, we are instructed to give that one answer: the right the correct… It is not really the training which you require to coach your brain to be innovative, to think critically, to think outside of the box. Critical thinking and innovation. Thinking hats and creativity." – Academic from FoE

"It doesn't mean that because we encourage critical thinking, the critical aspect, the scientific and science thinking we don't encourage the arts, the open thinking or creativity. On the contrary, for me they are one

and the same. We can't have one without the other. They're both very important to form the engineer of the future. The technologist of the future." – Academic from FoE

The two academics interviewed also seem to believe that solving problems across different disciplines can help foster creativity. This is a sensible thought as it places students in a mindset where knowledge transfer and inter-disciplinarity is being encouraged, unlikely connections are therefore more likely to be made and more creative ideas generated.

The academic from the FfBE cautions that the digital aspect of new technologies may hinder creativity if it is allowed to cap design skills. Digital technology should be used to boost creativity instead – by allowing even ridiculous options to surface, even if these are discarded, they may still spark ideas. This argument is very much in line with the ideas expressed by several authors. According to Charlesworth (2007), the use of CAD tools does not aid in the production of design suggestions which are precise and produced efficiently. When using CAD tools, users tend to focus more on the use of the tool rather than on the design considerations and evaluations (Isa & Liem, 2014). The value of CAD in the initial phases of the design process where design ideas are still being generated is therefore quite low (Charlesworth, 2007; Isa & Liem, 2014). It is in the later phases of the design development where the use of CAD can be beneficial since it can help in fine-tuning the design and choosing the final concept (Aldoy & Evans, 2011). Nevertheless, there are scenarios where the use of CAD tools, even in the early stages of design development can be helpful. This depends on the education and training received by the user. Expert users can visualize designs mentally and thus may be able to use CAD tools to do iterative work and refinements (Liem, 2012).

(Charlesworth, 2007; Isa & Liem, 2014; Aldoy & Evans, 2011; Liem, 2012)

"I think AutoCAD is really useful for production of drawings, but not for the design development… certain tools are actually detrimental for creative thinking and design thinking because a lot of times... they're easy to learn, so before it was like Maya and 3DMax, very difficult to learn, the learning curve was very high, so building a model and developing the project through sketches and physical models was the way forward. But then you'll see you kind of work with the site, you understand the scale… You work with the physical model, your working model, you understand the curvature, you understand the materiality, you understand gravity – that's probably the most important aspect. When you switch... curvature disappeared because SketchUp doesn't allow you to do curves. So, then what happens is what is considered as instrumental knowledge, the knowledge of the tool, caps your design skills. " – Academic from FfBE

"...using digital tools for computerization is not giving you anything for design process. Using digital tools for computation, for design process, for kind of modelling your logic, for testing your logic... So, if I'm model in Grasshopper, my computational, my geometric logic, then I can come up with options I didn't anticipate... I can have probably some ridiculous unusable options, but sometimes some of those ridiculous ones kind of create this click, that's it. You know, kind of allow you to change the perspective in a way." – Academic from FfBE

"...we have digital tools available in Malta. Companies do have CNCs and where they struggle is to go beyond these, kind of, pre-set commands…" – Academic from FfBE

4.6.1.2 Iterations

A true design process is iterative.

"...with every design process, if it's not... computerized, but it's a true design, with every cycle, because design is a lot of iteration, right? Go back." – Academic from FfBE

As one repeats the design cycle, their design knowledge in relation to several aspects of the product or project grows. The designer then has the important task of linking knowledge from diverse aspects together to come up with the optimal solution.

"...with every cycle... if you're doing material investigation and maybe bending something, now I know what material will do, but what will, let's say, the machine itself allow me to do? Now I know more about the material, more about machine. How do I marry one to the other? So, I think it kind of forms this circular loop. I would put them all under the umbrella of design knowledge, both of them. So, the design knowledge grows with every iteration and that's why I think design should be both sketching on paper and prototyping on working models. Kind of, it needs to come out. Then maybe comes, you know, digital modelling and evaluation. And then... it's tested. And then it's probably going to fail. Now we know,

and then we go again. So, I think it's an iterative process, but they feed off each other." – Academic from FfBE

4.6.1.3 Aesthetics and optimization

Aesthetics and optimization also form part of the design process. Optimization, in fact, features in Vincenti's (1990) design instrumentalities category of engineering design knowledge (Ankiewicz, De Swardt, & De Vries, 2006). The connection between aesthetics and optimization may not be apparent immediately. However, the academic from the FfBE explained how the trend in building design is shifting from being dominated by star architects and star architecture to designs that emerge from optimization of the material properties and forces. They mention that the process of optimization was not merely present during the design process, but it carried over through to the manufacturing stage where several versions of the project had to be constructed and tested to come up with a final design that was not just structurally sound, but also aesthetically pleasing. This kind of optimization is not just present in architecture, the mechanical engineer from industry also mentioned that optimization needs to be carried out on products to ensure that they can be manufactured using a specific technology. This is what according to them, can be used to make learning how to use a particular technology more interesting.

"So, let's say 20 years ago, architecture was dominated by star architects. Zaha Hadid, Frank Gehry, like Bilbao Museum, you know, like aesthetics, iconic building, like star architecture and iconic building, and now the switch is more kind of grassroots level, bottom up. So, things like working with communities, working with participatory design,

investigating material properties so materials would do what they're meant to do." – Academic from FfBE

"So, aesthetics almost, not take a second place, but the aesthetics come out of a process. It's not "I want it to look like this", it's more like optimizing the form with the forces, optimizing the material to work with the properties of material, and then to a certain extent, buildings end up looking organic and curvilinear, but not because necessarily that was the intent, it's because that kind of emerged from the process." – Academic from FfBE

"So, we did an interesting project... we managed to pull off quite a sizeable pavilion with a desktop size CNC router... it was a nice thing doing everything in house and obviously we had to do a lot of tests... It was a lot of kind of trial and error. The first one fell to bits and then we did it again and then optimizing the shape, the rotation." – Academic from FfBE

"3D printing ... someone who's never used to technology, tell them your problem isn't just to learn what 3D printing is and print something and whatever, your problem is, I have this design and I want to optimize it for 3D printing. How am I going to do it? So having that objective helps you learn a lot more about the technology than if you just show them on a 3D printer, told them, here's how you slice it, whatever. So, it's a hands-on and giving a problem to solve related to the new technology, I think." – Industry Professional with Mechanical Engineering Background

4.6.1.4 Modelling, prototyping and evaluation

The sub-theme of modelling, including its associated codes, which have already been discussed under the 'Knowing your Basics' theme, also forms part of the design process and design thinking and is thus being discussed under this sub-theme. Modelling and prototyping help in the management of the design process and help with the evaluation part of the design process (Broek, Sleijffers, Horvath, & Lennings, 2009; Isa & Liem, 2014).

> *"...there is the evaluation aspect and even that is important that we learn that listen, once you develop something, you have to test it to make sure that it conforms with your requirements." – Academic from FoE*

In general, a model is regarded as a less mature, less defined version of a final product and comes at an earlier phase of the design process (Isa & Liem, 2014). Models can be both physical and digital depending on the aspect being modelled and the questions that the designer is seeking to answer through the creation of the model.

> *"...we still try to push students... to develop physical models and then translate them into digital models that would help them build more. You know, it's a back-and-forth process." – Academic from FfBE*

Prototyping occurs when the design process is at a more advanced stage and a prototype is normally expected to have functionality similar to the final product (Isa & Liem, 2014). The engineer from industry in fact, mentions that their new prototyping lab includes various technologies which would allow them to even test the manufacturability of products – an important aspect of prototyping (Isa & Liem, 2014).

"...now we're introducing a prototyping lab, which is to do what 3D printing can't always achieve. So, it's got things like desktop injection moulding, surface decoration, laser cutting, so it adds a little bit more capability as well and it allows us to quickly turn if there isn't any time to lose. Some days when we're quoting projects, clients want things done much quicker. The ability to make things a bit more quickly at a lower cost somewhere between a model and a prototype tool is invaluable." – Industry Professional with Mechanical Engineering Background

It's interesting to note that prototyping was often mentioned in connection to 3D printing by the interviewees. This comes as no surprise since 3D printing has greatly improved the speed with which prototypes can be created as also mentioned by the mechanical engineer from industry. The academic from the FoE also mentioned that while 3D printing is important for prototyping, it is also valuable for making one-off components such as machine parts. This opens the door to many possibilities related to customization.

"...3D printing as a prototyping has been a very big, you know plus because there was nothing to compare it to, there was handmade model making which can't compete." – Industry Professional with Mechanical Engineering Background

"3D printing is very important because we use it for prototyping, yes, but we use it even to build machine components" – Academic from FoE

4.6.1.5 The initial phases of the design process

If a simplified and generic form of the design process such as explore-design-make-evaluate is considered, one will soon realize that while interviewees did mention the formulation of the problem and data collection as part of the design process, they did not place much emphasis on these, leaving the ‘explore’ phase somewhat neglected. Also neglected is the more recently introduced concept of ‘empathize’ that finds its place even before the explore phase in contemporary models of the design process to make the design more human-centred (Doorley, Holcomb, Klebahn, Segovia, & Utley, 2018). Knowing where to find knowledge was mentioned and is in fact one of the codes under the theme ‘Types of Knowledge’, however, it is almost disappointing to realize that this very important part of the design process is almost regarded as something which can be easily completed if one knows where to find knowledge. Only one interviewee made a brief comment about data collection, however, this hardly does justice to the complexity and importance of this step to the design process.

> *"To understand things like sensors, data collection, data, the perception of data, right, how we understand data, how do we collect data…" – Academic from FoE*

One reason for this apparent neglect of the initial phases of the design process by interviewees may be that the interview questions were more focused on the use and nature of new technologies. New technologies may be perceived as either not having a major role to play in the initial phases of the design process or their role may be taken for granted in the research phase. An example that comes to mind is the use of the Internet to conduct research and disseminate questionnaires that would help to develop a product – these have become so pervasive in today's way of collecting data that they may have been taken for granted and not mentioned during the interviews.

An alternative reason for seemingly assigning less importance to the 'explore' phase of the design process is that since the interviewees are so accustomed to the design process and can be considered experts – they do this step inherently and implicitly – and thus did not feel compelled to mention it during the interview (Woolfolk, Chapter 9 Complex Cognitive Processes, 2016).

4.6.2 Problem-solving

Problem-solving, as a skill, was already discussed in section 4.5.2 under the 'Constructivism' theme. However, this theme of 'Mindsets (ways of thinking)' and specifically, the sub-theme of 'Design Process and Thinking' are inextricably linked to problem-solving (Simon, 1996; Ankiewicz, De Swardt, & De Vries, 2006) – very often a design process begins with a problem that needs solving. Hence problem-solving as a skill was also linked to this theme.

4.6.3 Analytical and critical thinking

A designer, engineer or technologist needs to be able to think analytically and critically to solve problems. This was also linked to the ability of questioning things. The identification of this sub-theme came as no surprise – critical thinking features in educational debates very often and is usually not associated to a specific discipline. The National Curriculum Framework for All (NCF) lists analytical, critical and creative thinking in the first of six general principles that form its foundations (Ministry for Education and Employment, 2012).

"For me, design and technology is meant to lead towards the engineering. It's meant to prepare mentally, that engineer to start to think analytically, sequentially, in a well-ordered manner, scientifically, to a degree…" – Academic from FoE

"...you're given a problem, you're given a task, and you have to critically think how we're going to solve that problem." – Academic from FoE

"I would want to learn how to question certain things to be able to reason them out alone in future." – Industry Professional with Structural Engineering Background

"Being able to question… not being the dummy, like, you know, accepting whatever you're getting back, so being able to challenge what you're getting back from a program and question, does this make sense? I think having enough self-confidence, or enough, let's say common sense to realize that if the answer is wrong. There's something wrong..." – Industry Professional with Structural Engineering Background

This skill is not something which students can be expected to master at one go – students need to be trained and guided in analytical and critical thinking. Interviewees placed an emphasis on thinking of solutions that do not repeat already existing ones.

"Just start from something small and then you build on that. You can't expect to give them a big problem and immediately, from day one,

they're going to get there. Slowly, little by little, they need to be nurtured to be critical, to think." – Academic from FoE

"...the teacher becomes instrumental in leading because then the teacher leads, not instructs, because the second you instruct you have one solution. The second you say you have to do ABC. Nobody will do D or E or think about Z. The teacher has to lead, "listen, you need to achieve this". How? Think, be critical, explore." – Academic from FoE

"We are not instructed to think, we are instructed to give that one answer: the right the correct... It is not really the training which you require to coach your brain to be innovative, to think critically, to think outside of the box. Critical thinking and innovation. Thinking hats and creativity." – Academic from FoE

"...we encourage students a lot, especially at master's level, to rethink everything… we do need that level of rethinking everything..." – Academic from FfBE

Openness was a value that was highly prized in relation to analytical and critical thinking. Interviewees referred to openness in slightly different ways. For example, for the academic from the FoE, openness meant incorporating knowledge from other disciplines into solutions. The academic from the FfBE linked openness to the formulation of design problems in a more open manner and a willingness to start from scratch in order not to repeat existing solutions. The industry professional with a mechanical engineering background spoke about being open to new technologies. They related this to being able to view problems under a new light such that if there is a more suitable process for achieving a desired goal, it can be thought of and utilized. The industry professional with the structural engineering background spoke of openness in terms of always being willing and ready to learn even though a current solution may already be satisfying a specific need.

Refer to coded excerpt AFoE3 in Appendix D – Coded Excerpts from Interview Transcripts

"I think necessity for analytical thinking and creative thinking so kind of, openness...the crux of design, is formulating the problem that we are designing for, and I think that possibly, with current education, it's a lot of kind of repeating what we see, and I think new technologies allow us to start from scratch that's why analytical thinking is necessary... So, it's not the question of like "OK, we need to design, I don't know, vacuum cleaner". No. "We need to remove dust from this room". So, you start really rethinking the problem and then contemporary technologies will allow you to test it on the level of software analysis." – Academic from FfBE

"So new people coming in with a new view to new technologies is definitely going to help because when they tackle a problem, they don't just have one tool at their disposal... Right now, all they see is, OK, we got a new project, how are we going to injection mould 5000 pieces? Because that's the only thing available to them." – Industry Professional with Mechanical Engineering Background

"… being willing to learn constantly, being open to new technologies and new ideas and having interest to say, maybe fine this

program works for me, but maybe there's a better idea nowadays, which can help me be more efficient. Being open to that." – Industry Professional with Structural Engineering Background

4.6.4 Speed and efficiency

In one of the quotes mentioned in the previous section, the mechanical engineer from industry said that there is a mentality to immediately turn to the technology that is currently best-known when presented with a new problem. They mentioned that currently, people in their industry will immediately think about how to produce 5000 parts by using injection moulding, indicating that other technologies are not even considered. In their own words:

"...the established technology is always going to have a foothold and it's always going to win out in the short term." – Industry Professional with Mechanical Engineering Background

While this shows that there is lack of critical thinking, it may also be the fruit of the culture within the industry – a culture which prizes speed and efficiency over analytical and critical thinking. Very often these two mindsets are at odds with each other. In industry especially, one often needs to strike a balance between the two. Both industry professionals spoke extensively about analytical and critical thinking as well as about speed and efficiency. The D&T HoD also spoke about speed and efficiency to a lesser extent.

The mechanical engineer from industry spoke of 3D printing and additive manufacturing as being a very useful tool to improve the speed and efficiency with which models or prototypes can be created. In their industry, this has been such a success that a whole prototyping lab was being set up to try to emulate the same speed and efficiency in other processes.

"...additive manufacturing as an alternative manufacturing solution for lean and agile manufacturing..." – Industry Professional with Mechanical Engineering Background

"...we can send over parts very quickly without having to ship them by air." – Industry Professional with Mechanical Engineering Background

"3D printing has the benefit of being quick to set up and so on, no CAPEX. So, there's definitely situations where 3D printing makes a lot more sense than injection moulding. Even with the technology surface finish and speed and technology there's opportunities..." – Industry Professional with Mechanical Engineering Background

"…handmade models used to take weeks to produce, we can have a 3D printed part overnight if we really wanted to." – Industry Professional with Mechanical Engineering Background

"...now we're introducing a prototyping lab, which is to do what 3D printing can’t always achieve. So, it's got things like desktop injection moulding, surface decoration, laser cutting, so it adds a little bit more capability as well and it allows us to quickly turn if there isn't any time to lose. Some days when we’re quoting projects, clients want things done much quicker. The ability to make things a bit more quickly at a lower cost

somewhere between a model and a prototype tool is invaluable." – Industry Professional with Mechanical Engineering Background

Another major contributor to speed and efficiency according to the mechanical engineer from industry is the use of software as evidenced by the below quotes. They claim that the current education system is not focusing enough on software, which is a pity as it has great potential to improve the efficiency of several day-to-day processes.

"It's software as well. Things we can do in software nowadays can introduce massive efficiencies into, you know, traditional processes whether they're soft processes, or whether they're hard process…" – Industry Professional with Mechanical Engineering Background

"...let's say you had to identify uniquely every part that you produced for the customer's sake, whether it's for security reasons or anti-counterfeiting reasons or whatever. If you have to try and do that with injection moulding and decoration, it would be a massive undertaking with many different moving components, much more opportunity for failure, very expensive. But if you do it with software – integrated NFC or QR, or anything like that – you're going to save so much money in the long run. You're going to save so much time and effort, and you're going to make it more adaptable to future." – Industry Professional with Mechanical Engineering Background

Refer to coded excerpt IPME1 in Appendix D – Coded Excerpts from Interview Transcripts

"...I think it shows a little bit of what's lacking in the engineering, manufacturing and design profession. You know this linking with technology, it's getting better, I mean at the last Chamber of Engineers event, you can tell that there's a clear interest towards that direction. But the ability for engineers to get their hands dirty with software side of things, be able to implement solutions over there." – Industry Professional with Mechanical Engineering Background

The last aspect of speed and efficiency that the mechanical engineer from industry spoke about was the trade-off that sometimes needs to be made between going into a lot of detail when using a problem-solving technique or learning a new software and getting to the point where it can be used effectively quickly. This excerpt also makes reference to the fact that design and problem-solving are often taught as a ritualistic, step-by-step process or an iterative cycle when in reality, this is hardly ever the case (McCormick, 1997).

"We were always taught a number of problem-solving approaches... They're all very formal and I don't think that they're bad... So, I think more of that. But we need to get faster at that kind of thing, there is no time in certain projects to sit down to do a proper function means tree, that needs to be done automatically. There's no time to do a DFX analysis with all the different variables. A lot of these things have to be taught, in a sense, this methodology, but enforcing the notion that you need to sit down, write down through the effects on a piece of paper, write down every single aspect of it, that's a bit of a slow-going process, and I think it turns people away as well when they're trying to learn a new

problem-solving technique." – Industry Professional with Mechanical Engineering Background

"Things move quickly. What is the most important thing that's going to affect what you're doing? And when it comes to a new technology, what are the most important parts of it?" – Industry Professional with Mechanical Engineering Background

"When you're doing a project, you also won't have enough time to learn a new technology from scratch. You are going to have to learn the parts that are relevant to you and the rest will have to go along kind of. So, it's that prioritization, in the interest of time." – Industry Professional with Mechanical Engineering Background

The structural engineer from industry also spoke about some aspects of new technologies which have improved their efficiency. They also spoke about how sometimes one needs to "waste time learning" – an interesting choice of words which shows that learning a new technology 'costs' time.

"So, there's the drafting side, which obviously helps in being much more efficient I must say. And if we were to compare ACAD with Revit, we can see that again, it's become a much more efficient system whereby we can design things in 2D and at the same time the building done in 3D at a faster state, you know we can have elevations and sections within minutes nowadays, as opposed to how it used to happen with ACAD." – Industry Professional with Structural Engineering Background

"Calculations before they were all by hand, I mean that's how we were taught at university. We had handmade calculations. I had thick pages of I don't know like a 13-page calculation just to conclude that a slab passes and now the click of a button you can solve that out so." – Industry Professional with Structural Engineering Background

"...you need to have time to learn, time to waste time learning, you know, and I think our generation isn't as fluent or let's say the younger generations with digital technology are much more, you know, efficient and fast than the older generations." – Industry Professional with Structural Engineering Background

The last interviewee to speak about speed and efficiency was the D&T HoD. They attribute several advantages to new technologies such as efficiency, accuracy, safety and cost.

"...what we teach students is the fact that thanks to these new technologies we're saving time, we're being safer… How? Because they can see that after making their cardboard models, after testing it out, they don't need to manufacture it. Then they just feed the information to our CNC and the CNC will build, will cut the material for them, quickly, accurately without too much danger for the students themselves..." – D&T HoD

"...new technologies are there to make our life easier. They make it less expensive, could be making it safer, could be making it quicker…" – D&T HoD

4.6.5 Computational thinking

Computational thinking is a mindset that came up during the interviews. The fact that computational thinking came up was not a surprise – Simon (1996) links classic design methodology to problem-solving theories from computer science and psychology. Computational methods are one of the means used to evaluate designs according to him (Simon, 1996). Computational thinking basically involves using logic to come up with all the possible solutions to a problem. Computers are very good at simulating logic therefore if the user's thinking can be transformed in a way that computers can easily understand it, computational thinking can make it easier to use software and digital tools. Both the academic from the FoE and the academic from the FfBE mentioned this type of thinking. The academic from the FoE spoke about how once this skill is acquired it can be transferred between technologies while the academic from the FfBE seemed to indicate that this skill can help organize the thought process in a more logical way such that the designer does not become overwhelmed with the possibilities. It also helps to later automate or have software do the process of 'thinking logically' instead of the designer.

Refer to coded excerpt AFoE2 in Appendix D – Coded Excerpts from Interview Transcripts

"I ask students to really understand the geometric logic of something they are developing, so once they fully understand, and we literally develop geometric logic as a step-by-step algorithm, you know, I start with… I don't know like a Polygon ABC, midpoint, maybe you know, connect… So, I tell them, develop an algorithm to the point where I follow line by line and I can actually, you know, develop that. Once we have that

then we can use Grasshopper, you know, because quite often they get tangled up into using Grasshopper as a modelling tool, which it is not. It's modelling of logic or processes. So, this is where I kind of always… My focus is as I said, not aesthetics, not evaluation, but the process, design process itself and logic behind it." – Academic from FfBE

4.6.6 Skills

4.6.6.1 Ability to change, old vs young generations and lifelong learning

The ability to change was identified as a sub-theme due to the number of times it was mentioned by interviewees and the fact that being unable to change can be a barrier to the diffusion of new technologies.

"...the key skill that one should learn is actually being able to change, being ready to accept change, rather than, I don’t know, knowing how to use CAD, which is a particular software right? I don't see that as the key feature because technology is progressing very quickly... So, it's not the software per se that I think is the most important thing to learn. I think it's more an attitude that we need to accept, to embrace, that listen, technologies will change, be ready to adapt. That is the key aspect that I wish for my students to learn, basically..." – D&T HoD

Some interviewees also mentioned that younger generations tend to be more open to change, perhaps because they were born into the digital era and new technologies have a more digital nature, so they are more intuitive for them to grasp.

“…if you see a 5-year-old today, if you give them a new device, they would need no paperwork, no explanation, just leave me alone, I will intuitively do this." – D&T EO

"Most of the time it's human resource issues, that's most of the of the barriers I believe… Sometimes it's the age, sometimes it's the mindset." – D&T EO

"...there is this perception that, it's either you're that kind of person that can indulge into digital work, or you're not. So that's a common feature, a common barrier sometimes, which it's mostly with the elder people, not the students. The students don't have that very much. It's just how you present it in the first place, I think." – D&T EO

Refer to coded excerpt IPSE1 in Appendix D – Coded Excerpts from Interview Transcripts

It could also be related to the phase of life they are in. Students are very often not as pressured with deadlines as people in industry tend to be, so speed and efficiency are not as high on their agenda – their job is to learn, they have the time to learn.

"...the older you get and the more into work and the more busy you get, I think it's harder to actually learn new things, and once you're comfortable with a system in an office I think it's really hard to change…"– Industry Professional with Structural Engineering Background

Another reason might be that since they are new to the discipline, there isn’t something which they are very familiar with already, so any technology is new to them.

"...students don't find it challenging to shift to a new paradigm of working because it's a new paradigm anyway for them..." – D&T EO

When one gains plenty of experience with a specific technology, odds are they will be less willing to give that up because they have become experts in it and can deliver results using that technology very quickly.

"But you find a lot of resistance internally and this is internally not even from clients about surface finish, the time it takes, but it's about planning and capacity though. So, if injection moulding never existed and there was only 3D printing people would adapt, but since they have existing, they know what's better. Then it's going to be a very long time until we can change over simply because of the incumbent technology kind of thing. So that is the biggest barrier, I think." – Industry Professional with Mechanical Engineering Background

The industry professional with the structural engineering background also made a very important link between the ability to change and lifelong learning.

"...being willing to learn constantly, being open to new technologies and new ideas and having interest to say, maybe fine this program works for me, but maybe there's a better idea nowadays, which can help me be more efficient. Being open to that." – Industry Professional with Structural Engineering Background

4.6.6.2 Self-efficacy, self-directed learning, and metacognition

The three skills discussed in this section feature heavily in Albert Bandura's Social Cognitive Theory. The social aspect of the theory posits that learners learn through observing other people who act as models (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016). The cognitive part also includes "thinking, believing, expecting, anticipating, self-regulating, and making comparisons and judgments" (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016, p. 439). According to this theory, personal, environmental and behavioural influences interact with each other during learning (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016).

Self-efficacy is one of the personal influences involved in the Social Cognitive Theory (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016). It is defined by Bandura as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives" (Bandura, 1994, p. 71). According to McLaren (2012), D&T has the potential to instil autonomous learning and metacognition in students. Half the interviewees made remarks which were related to self-efficacy. The academic from the FoE says that a learner needs to believe that they can learn something at any point in time.

> *"...you have the capability of knowing that you can learn that at any point in time." – Academic from FoE*

The D&T EO draws comparisons between some older people and some of the younger generation. They further elaborate about the current mentality of some students that just because they watched the teacher in class perform a task or someone perform a task on a video, they can perform the task themselves. While his point about the role of the teacher in showing students that there is more to learn is valid, research shows that even when students over-estimate their level of efficacy, they are more motivated to succeed because they are healthier and less depressed (Flammer, 1995; Seligman, 2006).

> *"...it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow. So, some people, even some teachers, would resist that a bit because they say listen, I'm not trained fully with the software, so their barrier is I'm not trained like I was with the particular hand tool for this, so they expect that training to be fully spelled and shown. Whereas the barrier is more at psychological one that people think that I have to have all the documentation in my hand to do this, whereas even if you see a 5-year-old today, if you give them a new device, they would need no paperwork, no explanation, just leave me alone, I will intuitively do this." – D&T EO*

> *"...there is a culture nowadays that even if you saw a YouTube video, I know it. Which is a problem. And let alone if you get an expert in front of you, the teacher, and so you listen, you use this machine, like this, like this, like this. So, I'm not an expert, I'm a super expert because I not only saw the video, I had the teacher telling me this. So, the teacher has the responsibility to make students realize that there are many ways to fail, and that's important." – D&T EO*

The mechanical engineer from industry has a very high opinion of engineering students' self-efficacy. They believe that engineering students believe that they will manage to find a solution one way or another.

> *"You tell them, OK, you have to develop a Python script which does this. So, it's not only teaching them Python, which is kind of secondary, it's also teaching them how to learn this new technology, for the sake of, you know, their problem-solving, so a person now complains "I've never used it before", but more than likely an engineering student is going to try and say, OK, I have three months and I have to learn this tool. They're going to find a solution for it one way or another." – Industry Professional with Mechanical Engineering Background*

A skill that needs to accompany self-efficacy is self-regulation or self-direction. This is because, as Bandura himself puts it:

> *"The rapid pace of technological change and accelerated growth of knowledge are placing a premium on capability for self-directed learning." (Bandura, 1995, p. 17)*

A self-directed learner is a learner who does not need a teacher to continue their learning journey and therefore they can continue learning throughout their life (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016). This requires both skills and a will to learn (Murphy & Alexander, 2000; Schunk, 2005). Metacognition, motivation to learn and being strategic are all qualities of a self-regulated learner (Perry & Rahim, 2011).

Once again, half of the interviewees mentioned self-directed learning as an important skill to have. The mechanical engineer from industry called it prioritizing the aspects of a technology that need to be learned, implying that at some point the learner would have completed an exercise in choosing which aspects are important. Woolfolk claims that part of being an expert is in fact knowing what is important and what to concentrate on (Woolfolk, Chapter 9 Complex Cognitive Processes, 2016).

"So that is really about prioritizing what you're going to learn and how you are going to learn it applicable to what you're trying to do. When you're doing a project, you also won't have enough time to learn a new technology from scratch. You are going to have to learn the parts that are relevant to you and the rest will have to go along kind of. So, it's that prioritization, in the interest of time." – Industry Professional with Mechanical Engineering Background

For students who are still developing their self-direction, it is important to provide some guidance as to what they might need to solve a problem. Both the industry professional with a mechanical engineering background and the D&T HoD point towards this kind of approach in the two quotes below:

"...first you give the problem and then you say OK, now if you want, I'm going to do a lecture where I explain what 3D printing is or a lecture on the basics of Python. Then they can decide. OK I need that because I've never done it before. Whereas if you just told them, I'm going to do a lesson on it, they say, why would I need this?" – Industry Professional with Mechanical Engineering Background

"I never teach students how to use a 3D printer. That's not my aim. I set up a project where they understand that 3D printing would be an ideal way to solve this problem. So should they need to use a 3D printer, there is when I start teaching how to use a 3D printer or what a 3D printer is. So, they have a general knowledge of what it is, but then I do not make students use a 3D printer. They need to feel the need to use the 3D printer, so then they'll obviously need to know how to use the software, so you know, having students identify the need and then accepting their questions and answering their question basically." – D&T HoD

Metacognition was also mentioned by the interviewees as a skill which needs to be taught.

"Then when you get older, giving them specific problems that are beyond their comfort zone and saying, OK go solve this. So, you have an engineering mechanical student, who you know, just uses computers for the sake of their work… Giving them a problem like, we do it in MATLAB, but you know it could be something else now. You tell them, OK, you have to develop a Python script which does this. So, it's not only teaching them Python, which is kind of secondary, it's also teaching them how to learn this new technology, for the sake of, you know, their problem-solving..." – Industry Professional with Mechanical Engineering Background

"...knowing how to learn... that is more important for me." – D&T EO

The academic from the FoE hit the nail on the head when they linked metacognition, being strategic and motivation to being a self-regulated learner who does not fall prey to panic.

> *"I'm constantly learning to learn. I have to learn how to learn so that when a new technology comes up or when a new development comes up, I can face that and say, listen, in order to do this I need to learn this, this, this and this and I don't let anything stop me and say, "oh, because I don't know that, I don't know this solution, uh oh!" and panic, deer in the headlights syndrome." – Academic from FoE*

4.6.6.3 Learning from failures

Some level of failure is bound to accompany learning experiences at some point (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016). According to Vincenti's (1990) categories of engineering design knowledge, 'tragic experience' also contributes to the sub-category of 'experience in design' (Ankiewicz, De Swardt, & De Vries, 2006). Some of the interviewees mentioned failure as part of the learning process and see this as being important to learning.

> *"...the teacher has the responsibility to make students realize that there are many ways to fail, and that's important." – D&T EO*

> *"I'm the type of person who would only learn something after quite a good number of mistakes at trying to do it. But then I would know it, because during that process I would have gotten to know better why or*

how to do it properly and probably I would have searched couple of times what it is that I would have wanted to know." – D&T EO

The D&T HoD understands that students are all different.

"What I believe a teacher should do is entice students. We cannot take all the students to one particular spot... and if you don't reach that particular point, you're a failure." – D&T HoD

Here the teacher also plays an important role – rather than focusing on the failure, the teacher should help the student identify and reinforce the smaller achievements that the student made even if they ultimately led to failure. This focuses the student's attention on growth instead of the difficulty encountered (Woolfolk, Chapter 11 Social Cognitive Views of Learning and Motivation, 2016).

4.6.6.4 Entrepreneurship

Entrepreneurship was a skill that was very briefly mentioned by one of the interviewees. The NCF identifies it as one of the skills which sustains learners as they navigate "the world of work" (Ministry for Education and Employment, 2012, p. 33). Entrepreneurship is one of the aims of education established by the NCF and features in one of the cross-curricular themes of the NCF (Ministry for Education and Employment, 2012). In recent years, there has been much attention to the field of entrepreneurship education both from the side of policy as well as from research (Lackéus, Lundqvist, & Middleton, 2016; Mandel & Noyes, 2016; Neck & Greene, 2011). The D&T EO, rightly so, calls entrepreneurship a 'transferable' skill:

"...other approaches like pitching design ideas, so it also enforces other skills which I think are more transferable in today's life because it's like a very, very entrepreneurial world, the word of technology nowadays, so it's an important skill which we're seeing." – D&T EO

4.6.7 Approaches

4.6.7.1 Minds-on approach

When people engage in technological activity, part of their purpose is usually to create artefacts (McCormick & Davidson, 1996). This contrasts with science, where the focus is the creation of knowledge and understanding of natural phenomena (McCormick & Davidson, 1996). Technological activity, therefore, can be said to have both a 'minds-on' aspect as well as a 'hands-on' aspect (McCormick & Davidson, 1996).

In their 1996 paper, McCormick and Davidson argue that this duality of the nature of technological activity together with the motivational effect the creation of products has on students can lead to a form of tyranny in classrooms where the hands-on aspect overshadows the importance of complex thinking processes that are involved in the design process and in problem-solving activities (McCormick & Davidson, 1996). Two of the interviewees mention this exact conundrum where they insist that the emphasis should be focused more on the intellectual process rather than on the outcome of the hands-on activity.

"...but that is where it gets dangerous in people's perception. Most people, when you tell them hands on, they think that they're actually, I don't know, cutting metal, actually welding things, actually... No. It is what

I am meaning is you'll give them a problem and they have to solve it. That aspect of hands on." – Academic from FoE

"It doesn't have to be hands on, because all we're doing basically is creating technicians but on theoretical... So, you're creating a technician who instead of using the hands on, the technician on the theoretical." – Industry Professional with Mechanical Engineering Background

4.6.7.2 Bottom-up approach, reverse engineering and design without make

The academic from the FfBE described how there has been a shift in architecture from a top-down to a bottom-up approach. So, whereas in the past, buildings were designed for aesthetic impact and then structures, and materials would be chosen later to make that design possible, the approach is now the opposite. The designer starts from the needs of the community, may even invite the community to participate in the design process, takes into consideration what materials are to be used, perhaps in relation to how sustainable they are and how sustainably they can be sourced, and works within what the materials and the community allow him or her to do.

Refer to coded excerpt AFfBE3 in Appendix D – Coded Excerpts from Interview Transcripts

On the opposite end of the spectrum, there is reverse engineering, which is a top-down approach mentioned by the D&T EO. In reverse engineering, the sub-systems are first analysed and then broken down further into components and parts with each iteration of the process revealing more information about the product. The sub-category of 'structured procedures' under Vincenti's (1990) 'design instrumentalities' category of engineering design knowledge is described as the division of an overall system into subsystems (Ankiewicz, De Swardt, & De Vries, 2006). Hence, the approach of reverse engineering is also recognized as contributing to engineering design knowledge. The D&T EO mentioned that this approach is now also being included in the curriculum. There is value in both approaches.

"We did reverse engineering approaches in a small task…" – D&T EO

A third approach that was mentioned was the design-without-make approach. This approach was introduced by Barlex (1999) and is based on the premise that when engaging in design-without-make activities, students' imaginations are not constrained by their making abilities or their lack of understanding of emerging technologies (Barlex & Trebell, 2008). It was later proved that this technique can boost creativity in the classroom (Barlex & Trebell, 2008) which was noted to be lacking by several authors (Hamilton, 2003; Kimbell, Creativity in crisis, 2000; Spendlove, 2005). The D&T EO mentioned a 'blue-sky thinking approach' – design-without-make is in fact intended to allow students to think beyond their technical and making capabilities to come up with more creative ideas (Barlex & Trebell, 2008).

"...things that are design only. So, you would start from a concept and dream big and try to get a realistic concept, not making it. That's ideal for also emerging technologies, because sometimes you need to talk about "what if?" "What if I add Bluetooth to this device?" But we don't want to go into the nitty gritty of exactly implementing a Bluetooth device. So, it's a blue-sky thinking approach." – D&T EO

4.6.7.3 Systems thinking

Systems thinking can help in the identification of connections between systems and understanding the complexity of systems (McLaren, 2012). The mechanical engineer from industry mentioned the importance of the consequences of decisions made on other parts of the process and mentioned that the approach should be more holistic, possibly looking at the entire lifecycle of a project or product. This is very much in line with the idea of systems thinking, which, according to McLaren (2012), is considered to be a core skill by many engineers. In systems thinking one tries to anticipate any consequences, even if unintended, and mitigate them in advance. It is a very valid addition to the list of approaches that can and should be taught through D&T.

> *"As things get faster, things get more integrated you are not just going to be dealing with the production problem, you are going to be having your upstream or your downstream people telling you what you're implementing here will have an effect on what we do later on and that will be a problem. So, you might design something that solves the problem in your short term, but in long term… So, I think it's that forward thinking, problem-solving as well, trying to be a bit more holistic." – Industry Professional with Mechanical Engineering Background*

> *"Don't just look at the specific problem that you have, try and understand what your decisions are going to do to the entire project or product lifecycle." – Industry Professional with Mechanical Engineering Background*

4.7 Types of knowledge

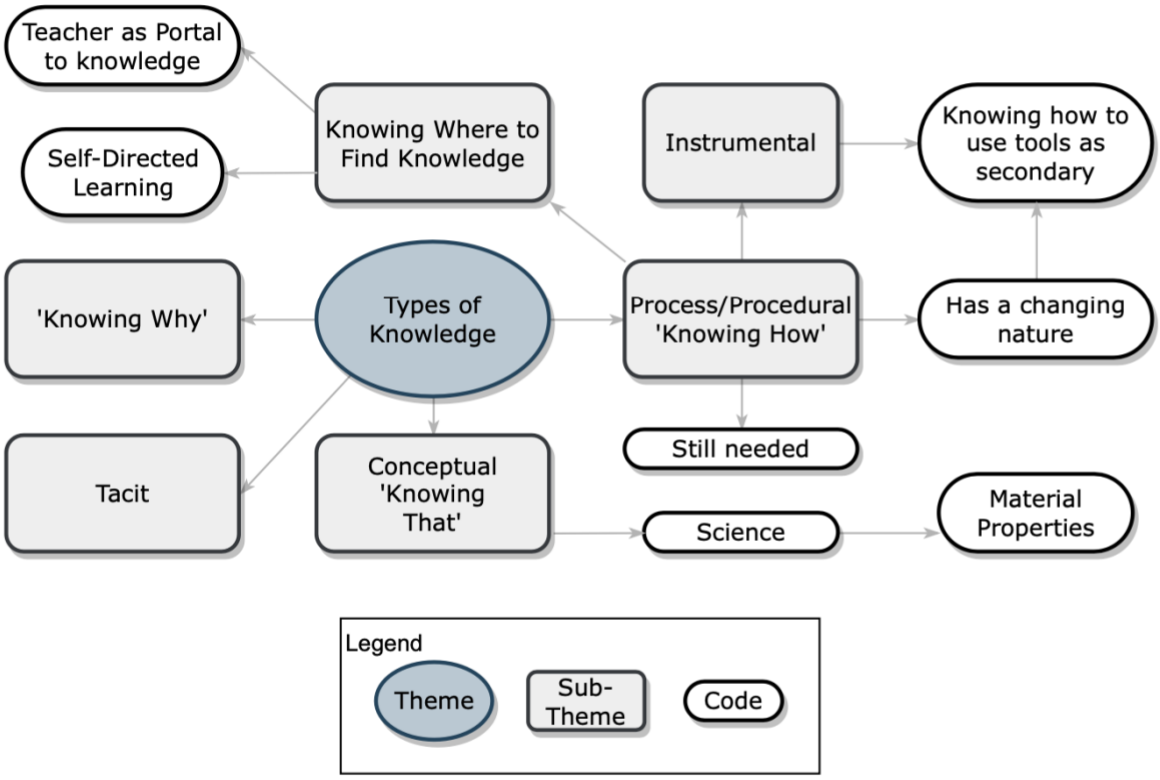

Figure 12 Concept map for 'Types of knowledge' theme

One of the interview questions asked whether interviewees thought that conceptual or procedural knowledge was more important. Responses varied with some interviewees claiming that they are equally important and others claiming that they value one type of knowledge more, even though it is very important to know where to find knowledge.

> *"...engineering course coordinators... at university level... insist that 'knowing that', the approach of knowing the foundational knowledge at first hand, like having the full book covered, before going into 'knowing how', is very important. Obviously, it is a higher level..." – D&T EO*

“Me personally, I’m a much stronger believer in procedural, but that’s me… If I went to everyone from my year of students and asked them, OK, what are the heat transfer equations? Myself, number one, I would not be able to tell you. But I know they exist... So, it's one of those things where knowing that they exist is good, so knowing that if I have a problem in my specific subsets that requires modelling of heat transfer, I know where to look. I know what I'm looking for.” – Industry Professional with Mechanical Engineering Background

With regards to procedural knowledge, interviewees pointed out that even though many traditionally manual processes have now been automated or computerized through CNC, CAD, CAM, and other developments, thus indicating that procedural knowledge has a changing nature, it is still important to have some knowledge of the traditional, manual process as this informs setting of parameters for the automated process and the limitations of certain processes.

Refer to coded excerpt AFoE1 in Appendix D – Coded Excerpts from Interview Transcripts

Some of the interviewees referred to knowledge of how to use tools without allowing any shortcomings or gaps in the knowledge to hamper the design process as ‘instrumental knowledge’. Due to the changing nature of procedural knowledge, they indicated that the knowledge of how to use tools is somewhat secondary to knowing the underlying concepts.

“…the challenge with new technologies is instrumental knowledge – knowing how to use software or digital tools or whatever, in a way

where you are using them and the lack of knowledge of how to use them does not cap your ability to express yourself. So, the crux for me is not the tool itself, it's the instrumental knowledge to use that tool" – Academic from FfBE

Another type of knowledge that was mentioned was strategic knowledge or knowing when to apply some form of knowledge (Gott, 1988; McCormick, 1997). The academic from the FfBE talks about strategic knowledge as knowing how to "marry one to the other" as they speak about material properties (conceptual knowledge) and machine limitations (procedural knowledge).

Refer to coded excerpt AFfBE1 in Appendix D – Coded Excerpts from Interview Transcripts

The D&T HoD also refers to strategic knowledge when saying that designing and making should go hand in hand.

"I believe that our students should be able to design and make because obviously they go hand in hand, so they'll be able to know the why and the how, because that's how obviously you get the best out of the material that you are, or your best out of your design, that you are building." – D&T HoD

In both the last two excerpts, the interviewees mention knowledge of material properties. The way they speak about it and mention its application during the design process is also reminiscent of the type of knowledge mentioned by De Vries (2003), that is, the knowledge of the relationship between physical and functional nature.

Interviewees also mentioned other types of knowledge such as tacit knowledge and the need that students have to know why they are required to learn certain material in school. These are further discussed in the respective sections that follow.

> *"...if I stick to our level, so let's say middle and secondary school, it's mostly striking the balance between 'knowing that' and 'knowing how'. But students will ask the question, "why do I need to know that this is this?", and "why do I need to know how to do this and this?" So, it adds the third column which would be, knowing why..." – D&T EO*

4.7.1 Conceptual knowledge – 'knowing that'

Conceptual knowledge or 'knowing that', has already been discussed under the theme 'Knowing your basics', specifically in section 4.2.1. It is obviously a very important type of knowledge that features heavily in the binary views of knowledge of Bayazit (1993), McCormick (1997) and Ryle (1949) discussed in the literature review (see section 2.3.3). Considering this, its place as a sub-theme within the 'Types of knowledge' theme is undisputable. The presence of this sub-theme under two of the themes shows how different themes can be connected to each other.

4.7.2 Process/procedural knowledge – 'knowing how'

Process knowledge, procedural knowledge or 'knowing how' was one of the types of knowledge mentioned during the interviews but many of the participants. They spoke about two specific aspects of this type of knowledge, that is, the fact that it is still needed and the fact that it has a changing nature. Two specific types of procedural knowledge were mentioned – instrumental knowledge, and knowing where to find knowledge. Interviewees also spoke about the role of the teacher as a portal to knowledge in relation to knowing where to find knowledge.

4.7.2.1 The changing nature of procedural knowledge

Procedural knowledge is perceived as being at a deeper or higher level by at least two interviewees who spoke about this aspect. In both cases, when interviewees speak about procedural knowledge as being 'at a deeper level', they also mention that procedural knowledge is knowledge that changes. Perhaps it is the changing nature of procedural knowledge that makes it deeper or higher level as students must extract concepts and common features of procedural knowledge to be able to apply it in diverse situations. This means that there is an additional step, or a leap, that students need to perform in their learning when dealing with procedural knowledge.

"…procedural is at a deeper level, more important… There is a formation over there, which is ingrained. You learn that all the time... the know-how knowledge is different and that is continuously changing. It changes with technologies, it changes with application, it changes with fields, etc." – Academic from FoE

Refer to coded excerpt DTEO1 in Appendix D – Coded Excerpts from Interview Transcripts

Considering the changing nature of procedural knowledge, the D&T EO claims that a new approach is required to teach how to use new technologies.

"...let's say how a digital manufacturing device like at 3D printing workflow contrast with a handsaw and a chisel. They're both tools, so I

would present them as they are both tools and the thinker and the mind is still the same person. But you cannot just say, OK, instead of cutting with this, I'm cutting with a 3D printer or similar. You have to take a different approach towards new technology." – D&T EO

4.7.2.2 Still need knowledge of process

This aspect of procedural knowledge relates to the fact that technologies have become more automated and controlled digitally in comparison to traditional technologies which used to be more manual. There seems to be an understanding that while it is still beneficial to know how the traditional, more manual, process used to be operated, the manual skill and perhaps in some cases, the required dexterity, does not need to be as refined as it used to be because digitization is now assisting the process.

Refer to coded excerpt AFoE1 in Appendix D – Coded Excerpts from Interview Transcripts

"The software doesn't automate everything for you, so whilst the machines are controlled more digitally, you still need to have the knowledge of the process then which supplements that." – Academic from FoE

Refer to coded excerpt DTEO1 in Appendix D – Coded Excerpts from Interview Transcripts

"...skills are quite simplified nowadays because it's different from trying to learn exactly how to hold a mechanical tool like a hand saw – you need to have a good position, and good posture, and good distance from

your bench. So that one would have typically required a specific guidance or instruction. Nowadays, with digital skills... you need less of an instruction to do it. The software will be guiding you throughout, either with a wizard or else with some sort of some help or assistance within the software... You don't even need to be particularly skilled technically, or particularly skilled artistically, which before were more accentuated..." – D&T EO

4.7.2.3 Instrumental knowledge

Instrumental knowledge can be considered a type of procedural knowledge since it consists of knowing how to use tools. What was most interesting about this sub-theme is that interviewees unanimously agree that knowledge of a specific tool is secondary to knowing the concepts required to use that tool.

Refer to coded excerpt IPSE2 in Appendix D – Coded Excerpts from Interview Transcripts

The academic from the FfBE cautioned against the use of digital tools as being potentially detrimental to creativity and design thinking since these have become so easy to use. They claim that when skipping steps of the design process and jumping straight into using digital tools, aspects of the thinking process involved in design are skipped and certain design knowledge is missed. There is also the risk of missing out on design opportunities because of being limited by what features of the program the user knows how to use or simply because the software does not allow them.

Refer to coded excerpt AFfBE4 in Appendix D – Coded Excerpts from Interview Transcripts

The academic's approach is to delay the use of digital tools and first teach students how to develop a simple algorithm. This helps to place the emphasis on the important part of learning – learning computational thinking in this case. It also helps shed some of the cognitive load. If students need to learn how to develop an algorithm and how to use a software at the same time, the cognitive load may be excessive.

Refer to coded excerpt AFfBE2 in Appendix D – Coded Excerpts from Interview Transcripts

Sometimes, to encourage students to learn how to use a new technology, challenging or specific problems at the right level need to be assigned. In the excerpts below, the interviewees highlight that learning a specific programming language is secondary to learning the kind of thinking associated with programming.

"Then when you get older, giving them specific problems that are beyond their comfort zone and saying, OK go solve this. So, you have an engineering mechanical student, who you know, just uses computers for the sake of their work… Giving them a problem like, we do it in MATLAB, but you know it could be something else now. You tell them, OK, you have to develop a Python script which does this. So, it's not only teaching them Python, which is kind of secondary, it's also teaching them how to learn this new technology, for the sake of, you know, their problem-solving..." – Industry Professional with Mechanical Engineering Background

"...you can make, but that is not the focus. The focus is how you are approaching that problem. That is the essential part." – Academic from FoE

Refer to coded excerpt AFoE2 in Appendix D – Coded Excerpts from Interview Transcripts

It was encouraging and refreshing to see that the interviewees from the education sector also shared the same view about new technologies. They realize that since technologies change rapidly, assessment cannot be based on how well a student knows how to use a machine, but rather needs to be at a higher level – about whether students have grasped the ability to learn new concepts.

Refer to coded excerpt DTEO1 in Appendix D – Coded Excerpts from Interview Transcripts

"...if I'm teaching them in 2022, how to start working on a 3D printer, and they go to work in 2028 for example, where the device will be completely obsolete and everything has changed… OK? so teaching them particularly how this printer works or how this technology is operated actually, is… It was good in 2022 because I could assess them, but until 2028 I need to leave something from that knowledge. So maybe the value I would have left, and maybe the foundation of knowledge. This skill will change for sure... what I would actually give importance in the teaching aspect, is that the moment you are teaching them is an experience and then experience is the only thing worth to spend your time on actually. It's

not worth studying by heart, something which, when you're finished with your assessment, will actually change." – D&T EO

"...we've got both a laser cutter and the 3D printer, but I always focus on the fact that the tool itself, is not an end to itself, so new technologies are just a means. So, when I deliver lessons to students, I don't focus on, listen, you have to use one of the latest emerging technologies, but obviously students, while discussing how we can move forward, how can we make this product even better, the use of current technologies will then be applied to a particular scenario given to the student." – D&T HoD

"...it's not the software per se that I think is the most important thing to learn. I think it's more an attitude that we need to accept, to embrace, that listen, technologies will change, be ready to adapt. That is the key aspect that I wish for my students to learn, basically." – D&T HoD

Refer to coded excerpt DTHoD1 in Appendix D – Coded Excerpts from Interview Transcripts

4.7.2.4 Knowing where to find knowledge

A skill that was highly valued by the interviewees was knowing where to find knowledge or how to do research. As one interviewee aptly put it, this is a type of procedural knowledge that is 'part of the problem-solving approach'.

"We were always taught a number of problem-solving approaches… they teach you how to address a problem, how to break it

down, how to look at alternative solutions, how to do research and so on." – Industry Professional with Mechanical Engineering Background

"OK, to do this I have to go and research what options are available to me." – Industry Professional with Mechanical Engineering Background

"...knowing that they exist is good, so knowing that if I have a problem in my specific subsets that requires modelling of heat transfer, I know where to look. I know what I'm looking for. That is, again, part of the problem-solving approach." – Industry Professional with Mechanical Engineering Background

"...you should be capable of knowing where to access that knowledge, which is nearly more important." – Academic from the FoE

Refer to coded excerpt DTEO3 in Appendix D – Coded Excerpts from Interview Transcripts

4.7.2.5 Teacher as portal to knowledge

Since knowing where to find knowledge is a learned skill, it needs to be taught. In fact, some of the interviewees spoke about the teacher being a portal to knowledge especially in the earlier phases of the learning journey.

"The teachers at that age, to a degree, are important to knowledge because at that age you still need the teacher as the portal to knowledge and "how am I going to do this?"" – Academic from the FoE

"At that age the teacher has to act as that portal. The teachers who's leading and saying, "listen, this is the knowledge which you are going to need". But not in detail applying it and so on." – Academic from the FoE

The mechanical engineer from industry and the D&T EO also spoke about allowing students to fail before stepping in with the knowledge they need. They see this as an important step which contributes to fruitful learning experiences that lead to students who are capable of self-directed learning.

"...when they're going off topic or off track, definitely off track, or when they're making a big mistake, you know or something, then they can come in and step in with real experience. So, once you've seen the problem it's easier to accept the solution rather than if I came in and before you even started, telling you, yeah, your 3D printed part, you should probably slice it at 0.2 layer height and give what settings to put in the machine, because that means they won't experiment and say why am I using this setting?" – Industry Professional with Mechanical Engineering Background

"I try to give out that approach to teachers as well. If they are the holders of how and every knowledge, they are set to not succeed, I think." – D&T EO

4.7.2.6 Self-directed learning

Knowing where to find knowledge is a skill that leads to students becoming self-directed learners. This aspect was discussed in section 4.6.6.2.

4.7.3 Tacit knowledge

Tacit knowledge is knowledge that one is sometimes not even aware they have. Alamäki (2018) claims that this knowledge is acquired from previous experiences and is extensively used by designers during a design process and when making decisions. Tacit knowledge also features in Vincenti's (1990) categories of engineering design knowledge under 'design instrumentalities' and specifically under the sub-category of judgmental skills (see section 2.3.6 of the literature review). In fact, the academic from the FfBE speaks about the knowledge that master masons have which comes from years of experience in handling stone. This helps them decide where to use specific stones.

"We have amazing master masons who are also disappearing, and they have knowledge of stones... So, from what I heard, like they kind of can knock on the stone and tell you, and touch its dust and tell you, oh, this is good for the foundation. There is kind of this tacit knowledge, knowledge that you don't learn through books." – Academic from FfBE

4.7.4 Knowing 'why'

The importance of knowing why something is being done or learned was already discussed in section 4.5.2 under the theme of 'Constructivism'. Perhaps the nature of this type of knowledge is more strategic or self-regulatory in that its role in learning and completing tasks is more motivational – knowing why one is learning something can serve to intrinsically motivate that person to pursue the learning activity as they perceive that they need the knowledge to succeed in what they are doing (Woolfolk, Chapter 12 Motivation in Learning and Teaching, 2016). It is also somewhat reminiscent of Mitcham's (1994 & 2001) manifestation of technology as volition where products, processes and systems are designed by 'willing' the knowledge of the designer into manipulating the physical world (Mitcham, 2001). While this may not be a traditional type of knowledge, or one that was expected to be mentioned during the interviews due to Mitcham arguing that it is often overlooked (Mitcham, 2001), it was interesting to see that many interviewees mentioned it.

4.8 The digital nature of new technologies

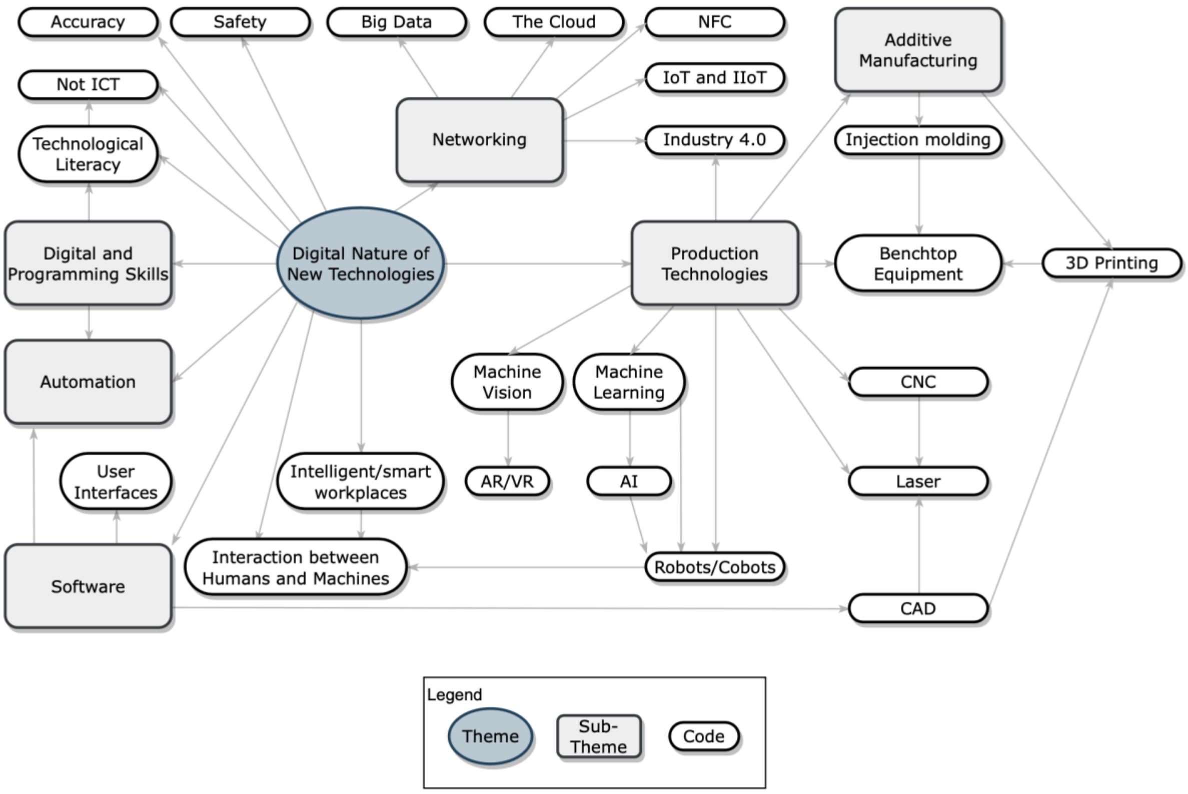

Figure 13 Concept map for 'The digital nature of new technologies' theme

When asked about the common features of new technologies, some of the interviewees went very straight to the point with comments like the below:

"The digital trend is across the board." – Academic from FoE

"...most of the time they involve digital technology, it is a common feature." – D&T EO

"...every time that we use, CNC equipment or 3D printers or laser cutters – all that is in the digital manufacturing sphere, is generally taken as new…" – D&T EO

Interestingly, in the quote below, the interviewee uses the terms 'technology' and program' – referring to a computer program – almost interchangeably attesting to how pervasive the digital nature of what are considered to be new technologies is.

"…one of the fundamental priorities is to know your basics. So before ever learning any new technology, you need to know what you're actually inputting into any new program that might be available." – Industry Professional with Structural Engineering Background

Other interviewees mentioned that technologies are now having computers or internet connectivity integrated to them which also falls under the realm of digital technologies.

"...tools that we used to teach, resources used to use, or other machinery like lathe for example, which were new at the time. Today, obviously, we have to move forward with integration of computers now moving also to the integration of Internet of Things." – D&T HoD

"...there is a very vast range of new technologies which students encounter every day. They are rather new and emergent, and they are the future – like embedded Internet in devices, like digital manufacturing is

also one of these areas, alternative technology, alternative battery technology, alternative energy." – D&T EO

The academic from the FfBE spoke about how digital tools have the potential to allow multiple variables to play out to enable new, creative solutions.

"...the user requires this switch in thinking. Digital architecture is really kind of, as I said, possibly giving up of a very specific solution and allowing multiple variables to play out. Like the ability of the tool, the materiality – the design process becomes all these capacities and constraints coming together. I think that would be a common feature maybe. Again, I'm not talking about automating what we know, but allowing digital tools or new technology, to kind of expose new solutions or new opportunities." – Academic from FfBE

"...I think digital tools, or technologies in general, allow us to pursue maybe these possibly crazy dreams which maybe become valid." – Academic from FfBE

4.8.1 Digital and programming skills

Since new technologies tend to be more digital, one would require digital and programming skills to operate them. The interviewees mentioned this aspect.

"Digital programming skills are underlying throughout." – Academic from FoE

"...you need to know your computer skills…" – Industry Professional with Structural Engineering Background

"…using digital tools... is a very easy way of how to entice students to develop a liking for the digital skills which are required…" – Academic from FoE

Refer to coded excerpt AFoE2 in Appendix D – Coded Excerpts from Interview Transcripts

Refer to coded excerpt IPME1 in Appendix D – Coded Excerpts from Interview Transcripts

The last two excerpts highlight two very important points. The first is that the kind of skills that are needed are not knowing a specific programming language but rather the way of thinking that is required to do programming. This requires some form of conceptual leap, and some knowledge transfer between situations. The second important point is that the current system may be lacking opportunities for learning digital and programming skills. In the quotation below, the D&T EO claims that in the new D&T syllabus the focus is not on coding even though students are introduced to a simplified form of programming through flowcharts, and they are also allowed to use other approaches even though these are not specifically taught at school.

"... in design and technology, we don't focus a lot on coding. So, flowcharts programming approach to microcontrollers is our main focus, but they are allowed to use any other approach as well." – D&T EO

Several authors agree that there has been a shift in technology education from craft or practical skills to technological literacy (Knight & Cunningham, 2004; Rossouw, Hacker, & De Vries, 2011). Rossouw, Hacker and De Vries (2011) define technological literacy as "what people need to live in, and control, the technological environment that surrounds us. This literacy comprises practical knowledge, reasoning skills, and attitudes” (p. 410). So technological literacy is not just about knowing how to operate a software, it is not merely the use of ICT as the academic from the FoE and the D&T EO explain.

"...we're not speaking about ICT here. So, this is the application of ICT to design and technology. For me there is a difference. Using digital technologies within design and technology is different from developing digital technologies or learning ICT" – Academic from FoE

"...there is a basic skill set that that one needs to have. It has to build up from your technological literacy… I'm not referring to typical ECDL skills obviously, because they should be core." – D&T EO

4.8.2 Automation

The digitization or computerization of technologies has led to automation of many processes which were previously manual.

Refer to coded excerpt AFoE1 in Appendix D – Coded Excerpts from Interview Transcripts

"With the use of certain technologies… that type of manual intervention has been automated, so you have measuring vision systems, you have calibration systems between the machines themselves, which allow the machines to calibrate themselves automatically..." – Academic from FoE

"...let's say how a digital manufacturing device like at 3D printing workflow contrast with a handsaw and a chisel. They're both tools, so I would present them as they are both tools and the thinker and the mind is still the same person. But you cannot just say, OK, instead of cutting with this, I'm cutting with a 3D printer or similar. You have to take a different approach towards new technology." – D&T EO

The increase in automation through new technologies has also been linked to an increase in efficiency which is highly valued by the industry professionals.

"…handmade models used to take weeks to produce, we can have a 3D printed part overnight if we really wanted to." – Industry Professional with Mechanical Engineering Background

Refer to coded excerpt IPME1 in Appendix D – Coded Excerpts from Interview Transcripts

"Calculations before they were all by hand, I mean that's how we were taught at university. We had handmade calculations. I had thick pages of I don't know like a 13-page calculation just to conclude that a slab passes and now the click of a button you can solve that out so." – Industry Professional with Structural Engineering Background

The structural engineer from industry goes even further by comparing a specific digital tool to a successive 'evolution' of that digital tool, saying that as the software evolved, it became even more efficient.

"ACAD is like, it's a relatively old, let's say old, program. I wouldn't say it's a new technology, but it's an ever-growing technology. I mean they went into Revit itself, so ACAD is now maybe eventually phasing out and hopefully we'll opt just for Revit eventually, but I still feel it's a very important technology to date." – Industry Professional with Structural Engineering Background

"...we can have elevations and sections within minutes nowadays, as opposed to how it used to happen with ACAD." – Industry Professional with Structural Engineering Background

Half of the interviewees, when speaking about automation and digitization of technologies, mentioned sketching specifically and claimed that they still see a lot of value in this activity even though the use of CAD has become so pervasive.

"I still believe in, not the old technologies, but the basics you know, like I can never say sketching needs to be phased out for new technologies because I still believe that sketching is fundamental for you to be good in a program, for example." – Industry Professional with Structural Engineering Background

"Sometimes people think that it's either sketching or working on a digital model on a computer. I experienced that myself as a designer where before I did only sketching, when I learned different software, I did not just do only digital designing, I started to merge my sketching back and forth with the digital modelling up to a point where sometimes you don't even catch a pencil while you're doing that, but it's still there, so one builds on

another they take different starting points, but it's an added skill and an added tool in the way I see it." – D&T EO

"...digital tools like AutoCAD, it's really how you use them. So, if you're going to automate a process you can do by hand, I don't think that tools will give you much. So yes, I can draft by hand, and I can draft in AutoCAD. Obviously in AutoCAD it's easier because of the printing and editing and all that... But also, I think something is also lost, especially maybe when nowadays a lot of students remove sketching because this kind of connection between your thinking and your hand and the pen. Uhm, I don't think that smoothness in kind of when you're seeking ideas or trying to make your thinking come out on paper, I don't think mouse or AutoCAD is easy to capture that." – Academic from FfBE

4.8.3 Software

The use of software was spoken about extensively throughout the interviews. The aspects of access and cost of software have already been discussed in section 4.1.2 under the theme 'Access and cost of technology'. Here, the use of software as a digital technology is discussed. Once again, the use of software was linked to greater efficiency.

"...without knowing the software side of things, that's a big limitation on how far we can go." – Industry Professional with Mechanical Engineering Background

"It's software as well. Things we can do in software nowadays can introduce massive efficiencies into, you know, traditional processes

whether they're soft processes, or whether they're hard process…"–

Industry Professional with Mechanical Engineering Background

Several software packages were mentioned specifically by name – these include AutoCAD, Revit, TinkerCAD, Grasshopper, Rhino, Maya, 3DMax, Sketchup, Photoshop and Lumeon. Most of these software packages are either CAD software packages or software packages used for generating and manipulating computer graphics and images and rendering. The software packages Robot and Microstran were also mentioned. These are structural analysis software packages. There seems to be a staggering amount of software use when it comes to design, and modelling of how a product or project will look which forms part of the conceptual design phase, and much fewer software packages used for carrying out calculations which forms part of the analytic design phase (Harris & Jacobs, 1995). The use of CAD is in fact regarded as a basic skill which opens opportunities for the use of many technologies.

"… you need another basic skill which is CAD." – Academic from FoE

"...we still teach technical drawing to our first years. We have CAD systems. Do we actually do technical drawing in real life and in industry? No, no one goes and gets a drawing board and stays drawing, we have a CAD system to do that. It speeds up everything." – Academic from FoE

"...the fact that you can perceive that object in three dimensions is fundamental. That leaves the door then, to CAD which leaves the door to 3D printing, to laser, etc." – Academic from FoE

One last aspect of software that interviewees mentioned is user interfaces. The main idea mentioned was that these do not vary much between software packages and once a user becomes familiar with one, it is usually relatively easy to use another.

Refer to coded excerpt IPSE2 in Appendix D – Coded Excerpts from Interview Transcripts

"...many of the design programs are fundamentally similar. It's just a question of interface at the end of the day, but once you learn one of them, I think it's much easier to learn the rest." – Industry Professional with Structural Engineering Background

4.8.4 Networking

One of the basic skills mentioned by the academic from the FoE is networking which is yet another digital field which is now becoming ever more present in new technologies due to the need for machines and equipment to have connectivity whether it's for data collection, logging, monitoring purposes, identification, for control or for communication and a myriad of other reasons.

"The knowledge of how to connect objects to each other via the Internet via any other protocol, etc. - communication." – Academic from FoE

Interviewees specifically mentioned a few technologies or ideas which involve networking, these include Big Data, The Cloud, Near Field Communication (NFC), Internet of Things (IoT) and Industrial Internet of Things (IIoT) and Industry 4.0

"...you have big data and anything which you can analyse and extract from that big data from the machines which you have over there." – Academic from FoE

"...let's say you had to identify uniquely every part that you produced for the customer's sake... if you do it with software – integrated NFC or QR, or anything like that – you're going to save so much money in the long run." – Industry Professional with Mechanical Engineering Background

Refer to coded excerpt DTEO2 in Appendix D – Coded Excerpts from Interview Transcripts

"...tools that we used to teach, resources used to use, or other machinery like lathe for example, which were new at the time. Today, obviously, we have to move forward with integration of computers now moving also to the integration of Internet of Things." – D&T HoD

"Even if I give an example to students how they order take away today. I mean, you can also mix and match between different restaurants from certain apps, so it is an industry 4.0 exemplified in everyday things…" – D&T EO

"For example, one of the items we are mentioning is Industry 4.0, right? It's not a manufacturing technology in itself, but it's an industry approach basically, and there's this big shift from the production techniques and methods found today to a more come customizable way of

working... this should change a bit the way you think about production scales, the way you think about batches, about just in time production… So, we are trying to instil these primary concepts of the new way the industry works. They don't contrast. I think they all build on what we have." – D&T EO

4.8.5 Production technologies

Production technologies having digital features are becoming more and more common. In fact, they featured heavily in the interviews. The D&T EO very aptly calls the fourth industrial revolution (Industry 4.0) "the new way the industry works".

Additive manufacturing technologies, specifically injection moulding and 3D printing were mentioned by interviewees together with laser cutters and machines which are controlled via CNC.

"...every time that we use, CNC equipment or 3D printers or laser cutters – all that is in the digital manufacturing sphere, is generally taken as new…" – D&T EO

The fact that many of these have become available in benchtop versions has made them more accessible (as discussed in the 'Access and cost to technology' theme) to more users thus increasing their popularity.

"...one thing that new technologies seem to benefit from that a lot of older technologies don't is that in the effort for people to get these technologies into more and more hands so that people can learn about them, use them more – so whether it's a student or whether it's a user – is

the miniaturization and barrier to entry." – Industry Professional with Mechanical Engineering Background

"...this type of benchtop equipment has improved greatly the accessibility of these type of instruments." – Academic from FoE

"...we managed to pull off quite a sizeable pavilion with a desktop size CNC router. It was 90 by something, I don't remember. It was meant to be a prototyping machine that we kind of abused to be a full-blown CNC." – Academic from FfBE

As expected, the star of the show is 3D printing. This technology has been mentioned several times throughout this chapter. Interviewees mentioned several advantages to this technology such as transferring digital files for printing to remote locations, the speed with which prototypes can be produced, the ease with which it can be set up and the opportunity to make one-offs. Furthermore, the fact that the technology has been simplified and thus made more accessible was also mentioned, together with the fact that knowledge transfer when using different 3D printing materials is also a possibility.

"...we can send over parts very quickly without having to ship them by air." – Industry Professional with Mechanical Engineering Background

"…hand-made models used to take weeks to produce, we can have a 3D printed part overnight if we really wanted to." – Industry Professional with Mechanical Engineering Background

"3D printing has the benefit of being quick to set up and so on, no CAPEX. So, there's definitely situations where 3D printing makes a lot more

sense than injection moulding. Even with the technology surface finish and speed and technology there's opportunities..." – Industry Professional with Mechanical Engineering Background

"3D printing is very important because we use it for prototyping, yes, but we use it even to build machine components" – Academic from FoE

"The way that you would prepare a CAD model for 3D printing now compared to then is absolutely the same, but the CAD tools have improved – more user friendly. The simulation tools and CAM tools which go with these machines have improved drastically. Before you needed to be an expert in order to have access to these. Nowadays. I'm not saying I'm not an expert, but it's a very simple thing. At the back of my office..." – Academic from FoE

"… once you learn the basics of 3D printing it's the process that changes and we have to learn the advantages and disadvantages of that process and all the nitty gritty of that process but at the end of the day, if you have a support structure for 3D printing, it's a support structure for 3D printing. If you're doing it for plastic parts or metallic parts…" – Academic from FoE

Other technologies that have been implemented into production equipment and were mentioned during interviews are machine vision and machine learning. These are also related to Artificial Intelligence (AI), Augmented Reality (AR) and Virtual Reality (VR) as evidenced by the following excerpts.

"AI is a skill, especially at secondary level. That is something that can be developed in future years. Right?" – Academic from FoE

"...we've also been working on intelligent systems from a machine learning point of view…"– Academic from FoE

"...now there's a walkthrough on how you feel in a building and what you see, you can see every single detail in 3D without actually building it nowadays." – Industry Professional with Structural Engineering Background

4.8.6 Interaction between humans and machines and intelligent/smart workplaces

A value which was mentioned by the academic from the FoE was understanding how humans interact with machines. This is very important to communicate the right information to machines and get them to perform in the way that is intended. There are also several ways in which it can be done as mentioned by the academic. Furthermore, we are now also seeing that some machines are developed in such a way that they are capable of some intelligence either through programming or through learning. The use of robots and cobots in industry and even beyond is no longer a thing of the future. Very recently there were reports of robots being used in a newly opened restaurant and supermarket in the local media (Diacono, 2022). This is also something that the upcoming generation, or the workforce of tomorrow, needs to become accustomed to.

"...understanding the ways that humans interact with machines, there's a value which is very, very, very important. A lot of the work we do is as well, in terms of user interfaces. To understand really how you are

communicating and passing information to machines, be it through a control panel, be it through a PC, be it through voice, be it through gestures, etc." – Academic from FoE

"… we're bridging these systems in order to develop the workspaces of the future. Intelligent, smart workspaces where humans and computers and machines work all together" – Academic from FoE

The D&T EO hints at these aspects more subtly but still mentions smart devices and industry approaches which will make it possible to customize not only products but also the way work is done.

"...what we are looking at, is the introduction of the concept of emerging technology. In that sense, it's not only the cutting edge, but we are surrounded with many smart devices around us in terms of able devices..." – D&T EO

"...one of the items we are mentioning is Industry 4.0, right? It's not a manufacturing technology in itself, but it's an industry approach basically, and there's this big shift from the production techniques and methods found today to a more customizable way of working." – D&T EO

A quotation that sums all of this up nicely can be found below:

"…collaborative robotics, cobots. So, robots in the same environment as humans, so without guards, without the need for having any stops, let's put it this way, when humans come into close contact with them. So obviously with that then comes the smart aspect, so AI and

internet of things like vision, machine vision systems to recognise humans, objects and everything in between. So, the idea is that we're bridging these systems in order to develop the workspaces of the future. Intelligent, smart workspaces where humans and computers and machines work all together. When we look at that as well, we've also been working on intelligent systems from a machine learning point of view, once you've connected everything, once you have access to all of your machines, you also have access to a lot of data, a lot of information. So basically, you have big data …. "What skills do you require in order to get here?" is a little bit of a very wide discussion. Obviously, there are the digital skills underpinning all of this." – Academic from FoE

4.8.7 Safety and accuracy

Interviewees from the education sector mentioned the fact that the digitization of some technologies has made them safer to use. It is understandable that these interviewees would be more concerned with safety since they are responsible for not just their own safety, but also that of the students they are teaching.

Another aspect which these two interviewees mentioned is the improvement in accuracy due to digitization of technologies. Since educators would be dealing with novice learners, it is expected that the accuracy of finished products produced by manual means could be low as the students would still be refining their skills. While this is completely normal and part of the learning process, it must pose some difficulties when assembling parts for a product or project. Digital technologies greatly reduce inaccuracies and facilitate these processes.

"...what we teach students is the fact that thanks to these new technologies we're saving time, we're being safer… How? Because they can see that after making their cardboard models, after testing it out, they don't need to manufacture it. Then they just feed the information to our CNC and the CNC will build, will cut the material for them, quickly accurately without too much danger for the students themselves..." – D&T HoD

"So, they can see that, listen, technology is helping but in many different ways. Being time, being safety, being accuracy, and cost…"– D&T HoD

"...new technologies are there to make our life easier. They make it less expensive, could be making it safer, could be making it quicker…"– D&T HoD

"...there's this dilemma where the technology teacher needs to be really skilled not to misguide or mis-show a technique, but then again, most teachers tend to seek further training, so they don't actually show something wrongly because there is safety involved." – D&T EO

"...the role of the teacher actually has to be to present technology in the right way, in a safe way and also to show that there is more training to get." – D&T EO

5 Discussion

This section focuses on correlating and contrasting the findings in literature, the interviews and the NCF document. In doing so, the research questions will be addressed.

5.1 Common features of new technologies

McKinsey & Company is a global management consulting firm that advises institutions ranging from private businesses to governments and actors in social sectors, has just published its technology trends outlook for 2022, in which its Technology Council pinpoints and decodes fourteen of the most noteworthy technology developments in the current world (McKinsey & Company, 2022).

The report classifies AI, advanced connectivity, future of bioengineering, and cloud and edge computing as “mature technologies” which are “closer to a state of mainstream adoption” (McKinsey & Company, 2022, p. 5). Another grouping of technologies is those which are related to sustainability and includes the future of clean energy, the future of sustainable consumption and the future of mobility (McKinsey & Company, 2022). This group has seen much innovation, interest and investment recently (McKinsey & Company, 2022). The last category is dedicated to emerging trends – these are still digital tools, however, they are somewhat novel and have not established themselves yet (McKinsey & Company, 2022). The category includes “industrializing machine learning, immersive-reality technologies, trust architectures and digital identity, next-generation software development, and quantum technologies” (McKinsey & Company, 2022, p. 5).

Table 4 lists the technologies identified by McKinsey & Company (2022) and the technologies or concepts mentioned by the interviewees who took part in this research. Technologies listed on the same row are equivalent or very closely related.

Table 4 List of new technologies identified by McKinsey & Company (2022) and technologies mentioned by interviewees

Technologies identified by McKinsey & Company (including brief overview)	**Technologies or concepts mentioned by interviewees**
Advanced connectivity – general improvements in networking capabilities. Includes smart sensors and IoT devices.	Networking (mentioned extensively by academic from FoE) Big Data IoT Sending over 3D files for printing at a remote location instead of shipping parts by air (as mentioned by industry professional with mechanical engineering background)
Applied AI – use of AI in machine learning (ML), computer vision, and natural language processing applications. Leads to automation and augmented capabilities. Used in autonomous machinery, robots, computer-vision enhanced safety procedures and 3D design optimization software.	AI Automation Robots and Cobots Machine vision Intelligent/smart workplaces 3D modelling and simulation software packages such as CAD packages and other software used for image processing and manipulation.
Cloud and edge computing – improvements in computing and data storage capabilities. Networking technologies and IoT work synergistically with this technology to extend its applications.	The Cloud

Immersive-reality technologies – spatial computed used to recreate physical spaces, add in features and make interactions with the latter possible. Includes AR, VR and mixed reality (MR)	AR and VR Creating virtual walkthroughs through buildings (as mentioned by the structural engineer from industry).
Industrializing machine learning – automating ML and applying it on a larger scale. Can decrease production times by as much as 90% (from proof of concept to product) and reduce development resources by up to 40%. Requires both software and hardware solutions.	Production technologies such as robots and cobots machine vision and machine learning Automation Software
Next-generation software development – enables non-technical people to develop software solutions. Includes AI-pair programmers (the equivalent of predictive text but for writing code), low-code and no-code platforms (e.g. visual programming with pre-written blocks of code chosen through a graphical user interface), and automated testing.	Software and improvements in user friendliness of software and user interfaces. Digital and programming skills Flowcharts approach to programming (mentioned by D&T EO) Light coding which allows automation of day-to-day processes through apps or similar platforms (as mentioned by the mechanical engineer from industry)
Quantum technologies – use of quantum mechanics to calculate complicated solutions at speeds much higher than traditional computers. Can improve security of networks and sensitivity of sensors.	Cybersecurity (mentioned by academic from FoE)
Trust architectures and digital identity – a more secure way for businesses to store, manage and analyse sensitive data. The use of biometrics and devices for logging into applications instead of just passwords is an example of digital identity technology.	Anti-counterfeiting measures (mentioned by industry professional with mechanical engineering background) Cybersecurity (mentioned by academic from FoE)

Web3 – authority on the internet is given back to users such that third parties are limited in how much money they can make by selling personal data. Includes ownership of digital assets such as non-fungible tokens (NFTs), blockchain technology, smart contracts, cryptocurrency, etc.	
Future of bioengineering – Includes gene therapy, tissue engineering and biomaterials that could treat previously incurable diseases, produce cultivated meat and provide alternatives to harmful chemicals.	
Future of clean energy – Energy solutions that are targeting net-zero emissions. Include renewable sources such as solar power and wind power, sustainable fuels such as hydrogen, long-duration battery systems, and smart grids.	Alternative energy and alternative battery technologies (mentioned by D&T EO)
Future of mobility – A move towards autonomous, connected, electric, and smart (ACES) technologies for transport. This move will disrupt markets but will also improve the efficiency and sustainability of both air and land transport of people and goods. Examples Include electric vehicles (EVs) and airborne drones. Improvements in battery technology will be pivotal in the future of mobility as will developments in AI and sensors to make independent decisions (such as in driverless vehicles).	Alternative battery technologies (mentioned by D&T EO)

Future of space technologies – space technologies have experienced lower costs due to reductions in size, weight and power of spacecraft. Satellites are becoming smaller and can orbit at lower heights. This opens possibilities for in-orbit manufacturing, power generation, space mining and human spaceflight	
Future of sustainable consumption – includes the use of goods and services that cause as little environmental impact as possible. This can be achieved either through low-carbon technologies or sustainable materials. Includes electrification of vehicles, new and sustainable building materials and techniques, sustainable packaging, product lifecycle considerations and circular technologies and optimization of electric power consumption.	Waste and sustainability Reusing construction and demolition waste (mentioned by both the academic from the FfBE and the industry professional with structural engineering background) Failure of contemporary materials which are CO2 intensive (as mentioned by academic from FfBE) Lifecycle analysis (mentioned by industry professional with mechanical engineering background)

Table 4 shows a high level of agreement between the new technologies identified by McKinsey & Company (2022) and new technologies mentioned by interviewees. Out of fourteen technologies mentioned by McKinsey & Company (2022), there were only three instances where the interviewed participants did not mention the same, equivalent or related technologies. This may be due to these technologies belonging to very specialized fields or fields which are not commonly addressed in D&T such as Web3, the future of bioengineering and the future of space technologies.

As declared by the McKinsey & Company (2022) report itself, most of the technologies identified by its Technology Council are digital. Another important grouping of technologies is the one related to sustainability. In a similar fashion, one of the largest themes identified through thematic analysis of the semi-structured interview transcripts is

‘The digital nature of new technologies’. Sustainability and waste-related issues, while still touched upon, were mentioned to a lesser extent by interviewees. These were discussed under the ‘Technology and communities’ theme. Shanks, Booth and Nolan (2014) also reported that the common features of new technologies include their digital nature and the prevalence of automation.

It is therefore apparent that the answer to the research question ‘what are the common features of new technologies in D&T?’ is that new technologies are digital and should support the automation of processes, and to a lesser extent, related to or supporting a view to sustainability.

5.2 Skills and values required to harness new technologies

One aspect that both interviewees and the literature agree on is that knowing how to use a specific technology is secondary to learning the underlying concepts of that technology. Very often, this requires a conceptual leak from superficial to deep learning (Keith Sawyer, 2014). This section of the dissertation seeks to answer the research question:

What skills and values are required to harness new technologies?

The answer to this question is complex. A summary of the skills and values required to harness new technologies as found in literature and as explained by interviewees is given in Table 5. Skills and values listed on the same row are equivalent or very closely related.

Table 5 Summary of skills and values required to harness new technologies as found in literature and as explained by interviewees

<table>
<tr><th>Skills and values required to harness new technologies from literature</th><th>Skills and values required to harness new technologies from interviews (related themes in brackets)</th></tr>
<tr><td>Design (McCormick, 1997)
Designing (Lucas & Hanson, 2014)</td><td rowspan="2">Design process and thinking (Mindsets (ways of thinking))</td></tr>
<tr><td>Designerly thinking (McLaren, 2012)</td></tr>
<tr><td>Curiosity (Lucas & Hanson, 2014)</td><td></td></tr>
<tr><td>Problem-finding (Lucas & Hanson, 2014)</td><td>Formulating the problem (Mindsets (ways of thinking))</td></tr>
<tr><td>Problem-solving (Han & Bhattacharya, 2001; McCormick, 1997)
Creative problem-solving (Lucas & Hanson, 2014)</td><td rowspan="2">Problem-solving (Mindsets (ways of thinking) and Constructivism)
Creativity (Mindsets (ways of thinking))
Innovation (Mindsets (ways of thinking))</td></tr>
<tr><td>Creativity (Han & Bhattacharya, 2001)</td></tr>
<tr><td>Generating ideas with others (Lucas & Hanson, 2014)
Collaboration (Han & Bhattacharya, 2001; Lucas & Hanson, 2014)</td><td>Multiple solutions (Mindsets (ways of thinking))
Collaboration (Cross-curricular learning and Technology and communities))
Communication (Knowing your basics)</td></tr>
<tr><td rowspan="4">Self-directed learning (Han & Bhattacharya, 2001)</td><td>Self-directed learning (Mindsets (ways of thinking) and Types of knowledge)</td></tr>
<tr><td>Independent learners (Access and cost to technology)</td></tr>
<tr><td>Professional development (Technology and communities)</td></tr>
<tr><td>Metacognition (Mindsets (ways of thinking))</td></tr>
</table>

Resourcefulness (Lucas & Hanson, 2014)	Knowing where to find knowledge (Types of knowledge)
Taking intellectual risk (McLaren, 2012)	*Although not coded as part of the thematic analysis, the academic from the FfBE mentioned "possibly crazy dreams which maybe become valid" and the academic from the FoE mentioned "to think outside of the box"*
Interconnecting knowledge (Keith Sawyer, 2014)	Interconnecting knowledge (Cross-curricular learning)
Pattern recognition (Keith Sawyer, 2014) Pattern sniffing (Lucas & Hanson, 2014)	
Transforming scientific concepts into intermediate concepts (McCormick, 1997)	Knowledge transfer (Cross-curricular learning)
System approaches (McCormick, 1997) Systems thinking (Lucas & Hanson, 2014) Recognizing interdependencies (Lucas & Hanson, 2014)	Systems thinking (Mindsets (ways of thinking))
Synthesizing (Lucas & Hanson, 2014)	
Analytical thinking (Han & Bhattacharya, 2001) Analysing (Lucas & Hanson, 2014)	Analytical and critical thinking (openness) (Mindsets (ways of thinking))
Critical thinking (Han & Bhattacharya, 2001; Keith Sawyer, 2014; McLaren, 2012) Critiquing (Lucas & Hanson, 2014)	
Open-mindedness (Lucas & Hanson, 2014)	
Visualising (Lucas & Hanson, 2014)	3 Dimensionality (Knowing your basics)
Sketching (Lucas & Hanson, 2014)	Sketching (Knowing your basics)
Making value judgments (McLaren, 2012)	

Ethical consideration (Lucas & Hanson, 2014)	
Decision-making (McLaren, 2012)	
Modelling (McCormick, 1997)	Modelling (Mindsets (ways of thinking) and Knowing your basics)
Adapting (Lucas & Hanson, 2014) Improving (Lucas & Hanson, 2014) Optimization (McCormick, 1997)	Optimization (Mindsets (ways of thinking))
Prototyping (Lucas & Hanson, 2014)	Prototyping (Mindsets (ways of thinking))
Testing (Lucas & Hanson, 2014)	
Re-thinking (Lucas & Hanson, 2014)	*Although not coded as part of the thematic analysis, re-thinking was mentioned by the academic from the FfBE*
Resilience (Lucas & Hanson, 2014)	Ability to change (Mindsets (ways of thinking))
	Self-efficacy (Mindsets (ways of thinking))
	Learning from failures (Mindsets (ways of thinking))
Quality assurance (McCormick, 1997)	
Reflection (Han & Bhattacharya, 2001; Lucas & Hanson, 2014)	
Evaluation (Han & Bhattacharya, 2001)	Evaluation (Mindsets (ways of thinking))
Self-evaluation (McLaren, 2012)	
Time management (Han & Bhattacharya, 2001)	
Project planning (McCormick, 1997)	

Lucas and Hanson (2014) *mention computational thinking as a pedagogy rather than a skill or value*	Computational thinking (Mindsets (ways of thinking) and Knowing your basics)
Shanks, Booth and Nolan (2014) *mention that new technologies are often digital and lead to automation therefore the need for digital and programming skills is assumed*	Digital and programming skills (Digital nature of new technologies and Knowing your basics)
Entrepreneurship (Lackéus, Lundqvist, & Middleton, 2016; Mandel & Noyes, 2016; Neck & Greene, 2011)	Entrepreneurship (Mindsets (ways of thinking))

Table 5 shows a high level of agreement between literature and the codes and sub-themes identified through thematic analysis of interview transcripts. Knowledge of the design process and designerly thinking features in both, as well as problem-solving and analytical and critical thinking with an open mind. These can be somewhat considered the pillars of the 'Mindsets (ways of thinking)' theme and were in fact identified as sub-themes. The design process is broken down into steps which are emphasized in both literature and the thematic analysis, these include formulating the problem or problem-finding, the possibility of having multiple solutions or generating ideas, modelling, prototyping, optimization (including adapting and improving), and evaluation. Other mindsets or skills which both literature and the interviewees agree that are important are the ability to change, self-efficacy and learning from failures which were related to resilience from literature, self-directed learning, independent learning, professional development, metacognition, systems thinking and entrepreneurship.

Specific skills used during designing and problem-solving are also common in both literature and the thematic analysis carried out. Most of these can be found under the 'Knowing your basics' or 'Cross-curricular learning' themes and include collaboration and communication, sketching, 3 Dimensionality or visualizing, interconnecting knowledge and knowledge transfer which was linked to transforming scientific concepts into intermediate concepts from literature. Finally, from the 'Types of knowledge' theme, the skill of knowing where to find knowledge was also emphasized by interviewees while in literature it was referred to as resourcefulness.

The list of common skills and values between literature and the thematic analysis carried out is varied. Some skills are definite and obvious examples of procedural knowledge. These have also been called hard or technical skills in literature (Litecky, Arnett, & Prabhakar, 2004) and include sketching, modelling, and digital and programming skills. Other skills are considered soft skills that make it possible to work with others and enable inter-social participation such as collaboration and communication (Seery, Canty, O'Connor, Buckley, & Doyle, 2016). Another collection of skills, while still falling under the category of procedural knowledge, are higher-order intellectual skills which can be further split into two:

1. Skills that can be regarded as processes and represented in a step-by-step fashion (even though, in reality, the steps may not be sequential, or the cycle might repeat itself) such as the design process, problem-solving and systems thinking. Seery, Canty, O'Connor, Buckley, and Doyle (2016) have termed these ways of thinking for holistic or intra-personal development.
2. Skills that are difficult to teach explicitly and for which an effort needs to be made by the teacher to model the behaviour. Very often these skills have a more tacit nature – it is difficult to determine whether the student has acquired them. Sometimes the students themselves may not even realize that they are

developing these skills. These include creativity, innovation, self-directed learning, metacognition, interconnecting knowledge, knowledge transfer, analytical and critical thinking, the ability to change and self-efficacy.

Below is a list with some remarks about skills and values which, while being mentioned in literature, seem to have been omitted by interviewees:

- Making value judgments: this skill points directly to the normative nature of technological knowledge and the fact that in technology, one can say whether a function is fulfilled well or not (De Vries, 2005). It was surprising that none of the interviewees mentioned this aspect of technological knowledge even though it is highly probable that they make value judgments very often in their work. However, they may be doing them so automatically that they may not be realizing that they do them and hence did not mention them.
- Ethical consideration: while waste, sustainability, product lifecycle and participatory design were mentioned, and one of the resulting themes is 'Technology and communities', interviewees did not seem to give much importance to ethical considerations or mention empathy in relation to design. From a philosophical perspective, this seems to indicate that the critical side of the philosophy of technology is somewhat of an afterthought for the key experts interviewed.
- Decision-making: some decision-making processes come naturally – such as choosing which idea to develop further after having generated several ideas as part of a design process. Other decision-making processes are more

strategic – such as deciding when to stop generating ideas. The whole design process can be said to be characterized by decision-making at every step and yet decision-making was not mentioned by interviewees. Perhaps the inevitability of decision-making is in fact the reason that interviewees did not mention decision-making as a skill.

- Quality assurance: the fact that quality assurance did not come up during the interviews, especially in the interviews with the professionals from industry, was quite surprising especially considering that many industries are now seeking to be ISO 9001 certified. In industrial and professional environments there is often a whole department or at least a person whose responsibility is quality assurance. This person or department usually interacts with people from the entire organization and conducts internal audits and other such activities. External quality audits are also quite common to maintain certification. Quality assurance is therefore very important in giving D&T students an authentic experience of technological activity. Apart from regulatory requirements, quality assurance also ensures that a product will not harm users so there is also a moral aspect associated to it.
- Reflection and self-evaluation: reflection, evaluation and self-evaluation should be part of every step of the design process; however, many depictions of the design process show evaluation as a last step in the design process and the step is often skipped or overlooked in both industry and educational settings (Johnson, 1997; Jones, 1997). This may be due to time constraints but also due to the perception that this step is less important than others in the design process.

- Time management and project planning: while interviewees, especially those from industry, gave a lot of importance to speed and efficiency, they did not specifically mention time management or project planning even though these aspects are surely present in both industry as well as the education setting where projects are assigned with deadlines and require planning for tools, materials, scheduling, etc.

As discussed throughout this section, there is a strong correlation between the skills and values mentioned in literature and those mentioned by the key experts interviewed. Most of the skills mentioned are intellectual skills, or soft skills, except for a few hard or technical skills which are considered basic. This is to be expected given that the nature of new technologies is more digital (as established in the previous section) and that this, together with automation, has taken over many of the manual skills that were required to engage with technology in the past.

5.3 Opportunities for learning D&T skills and values in the Maltese curriculum

To establish the opportunities for learning skills and values required to harness new technologies in D&T in the Maltese curriculum, the NCF was thoroughly read, analysed, and opportunities for learning the skills and values listed in Table 5 were sought. Since, the NCF does not just deal with skills and values but also with ideas relating to pedagogy, cross-curricular learning, etc., the themes identified in the thematic analysis were also sought.

Some of the themes identified in the thematic analysis are also present in the NCF at differing levels of detail while others are less prevalent. Over the next few pages, the prevalence of each theme in the NCF, except for the 'Digital nature of new technologies' theme[2], will be discussed.

Opportunities for learning most of the skills and values required to harness new technologies in D&T listed in Table 5 were found in the NCF (see Table 6 in Appendix C – Opportunities for learning D&T skills and values in the NCF). The skills and values for which opportunities were not found are discussed under their respective theme.

The 'Mindsets (ways of thinking)' theme consists of sub-themes and codes that are most closely related to skills and values. It is therefore the most relevant theme for answering this research question. The sub-themes of problem-solving, analytical and critical thinking (openness), design process and thinking, and ability to change are all emphasized in relation to technology education in the NCF. A lack of opportunities for learning these skills and values is therefore not envisaged. The NCF also refers to innovation, creativity, evaluation, optimization, systems thinking, entrepreneurship, metacognition, self-efficacy and self-directed learning several times indicating that these skills and values are held in high regard. While it is to be expected that some of the sub-themes or codes present under this theme may not feature in the NCF, it is rather disappointing that some others do not appear. Speed and efficiency are not mentioned in the NCF, but their absence is not of such great concern since up to secondary school level, speed and efficiency should not be the focus of education – these become more important upon entering the world of work.

[2] The only relation that this theme has to the NCF is the recognition of the importance of digital literacy in the NCF. The sub-themes and codes present in this theme are overly specific for a high-level document such as the NCF or are discussed under other themes. The purpose of the 'Digital nature of new technologies theme' was fulfilled in answering the first research question.

Modelling and prototyping on the other hand, are highly relevant to the design process and yet completely missing from the NCF. In a similar fashion, the idea of iterations and the iterative nature of the design process is lacking – the NCF merely mentions a vague idea of "cycles" (Ministry for Education and Employment, 2012, p. 35). Aesthetics were mentioned as part of the design process by one of the interviewees. This code, while present in the NCF, does not appear in connection with technology but is presented in relation to art. This can be considered a missed opportunity considering the emphasis that the NCF places on cross-curricular learning.

Moving on to the 'Cross-curricular learning' theme but remaining on the subject of art, it is worthwhile to mention that while the NCF often relates the fields of science, technology and mathematics together, hinting a move towards the STEM approach, art is never associated with these disciplines as is the current trend with the shift towards STEAM education. Perhaps it is a sign of the times in which the NCF was conceived – the shift towards STEAM education is rather recent. The rest of the codes under the 'Cross-curricular learning' theme, namely, collaboration, interconnecting knowledge, knowledge transfer, and appealing to students' interests, are present and emphasized by two of the main tenets of the NCF:

> *"…move away from an exclusively subject-based approach that favours fragmentation and compartmentalisation of knowledge to a more cross-curricular, thematic, inter- disciplinary and collaborative approach that reflects real life situations and encourages transfer of skills from one learning area to another."*

"…flexible learning programmes providing diverse and integrated learning experiences that cater for a wide spectrum of learners and which suit the interests and capabilities of individual learners within nationally accepted parameters."

(Ministry for Education and Employment, 2012, p. 31)

The NCF only makes a few fleeting but direct references to constructivism, however, mentions some of the components that make up this pedagogy several times. These include real life or authentic experiences as part of a cross-curricular approach, scaffolding as an additional support for learners and the importance to build on prior knowledge. The importance of timely feedback on assessment and having less prescriptive syllabi is also mentioned. Hands on experiences are also mentioned in relation to the learning area of Science and Technology which is laudable for the NCF. What's lacking however, is the aspect of a 'minds-on' approach which emphasizes the use of intellectual skills. Also lacking is the aspect of 'knowing why' which was discussed in relation to student motivation and the conception of technology as volition (refer to Mitcham, 1994 and De Vries, 2016). Problem-solving is mentioned several times both as a general skill and as a skill that is specific to a learning area or cross-curricular theme. This is congruent with the current views expressed in literature about problem solving as a skill. In the context of science and technology, "technological problem solving" (Ministry for Education and Employment, 2012, p. 8) is mentioned, however, it seems to be shrouded by the approach of scientific inquiry (see also Pulé, 2019) which may lead to the inaccurate conception that problem-solving in technology is merely the application of scientific concepts.

A discussion about the types of knowledge in technology is completely missing in the NCF. The sub-theme 'knowing where to find knowledge', which stems from the 'Types of knowledge' theme, is the only one mentioned in the NCF. In the context of technology education, conceptual knowledge, while not referred to specifically by the term 'conceptual knowledge', is mentioned in the form of 'science'. The message this sends is that conceptual knowledge in technology comes exclusively from science, specifically materials science. The occurrence of the word materials is underlined in the excerpt below which is extracted from the description of the learning area of Science and Technology as an example:

> *"…select appropriate tools, techniques, and materials; explore the qualities of materials; shape and combine materials and components... Their exploration of materials will include Resistant Materials, Electronics and Graphic Products." (Ministry for Education and Employment, 2012, p. 35)*

Moreover, tacit knowledge is completely absent from the NCF and so is the idea that knowing how to use tools is secondary to learning concepts and high-level procedural knowledge. The NCF mentions 'making' as if this is the only aspect of procedural knowledge in D&T. The fact that procedural knowledge has a changing nature is not acknowledged in the NCF. The fact that the world is constantly changing, especially due to the advent of new technologies, is however implied, and the emphasis on digital literacy is pervasive throughout the document. The normative aspect of some forms of technological knowledge is also missing – this stems from the limited view of the relationship between science and technology which in this case is that technology is the application of science. This view is also shared by Pulé (2019). As a high-level document, the NCF has major shortcomings in laying out foundations for the way that technology manifests itself as knowledge (refer to Mitcham, 1994 and De Vries, 2016).

The ’Knowing your basics’ theme has some sub-themes in common with the ‘Types of knowledge theme’. Conceptual and procedural knowledge have been discussed in the previous paragraph. The modelling sub-theme has also already been discussed. The sub-theme of communication is very much present in the NCF which includes aspects of communication between students as they construct understanding and communicating ideas. An important aspect of communication in D&T, that is communication through technical drawing, is however, missing from the NCF. The same finding was also reported by Pulé (2019). The sub-theme digital and programming skills has a high correlation with digital literacy in the NCF. The NCF recognizes the importance of digital technologies in the changing world and gives due importance to digital literacy. However, digital literacy does not encompass the broader aspect of technological literacy, neither does it encompass the skill of computational thinking. Additionally, while placing heavy emphasis on various types of literacy skills, the NCF does not mention knowing the language of a specific discipline which is an important aspect of being socialized into that discipline. This shortcoming was also noted by Pulé (2019).

The theme of ‘Technology and communities’ focuses mostly on the humanities philosophy of technology or the critical aspect of the philosophy of technology. In comparison to other themes identified through the thematic analysis of interview transcripts, it is not an expansive theme, meaning that this aspect of the philosophy of technology was not given as much importance by interviewees. While the NCF has a strong orientation towards humanities, there are instances where links to technology are made while other instances where the opportunity to link human aspects to technology were missed. The NCF makes valid links between technology and collaboration. Professional development is emphasized throughout the document, the message in this regard is clear; professional development is required by all educators at all levels and hence it can be said that the principle applies to technology educators as well. Education for sustainable development is one of the cross-curricular themes of the NCF. However, even though the findings in section 5.1 relating to the common features of new technologies indicate that they are ever more related to sustainability, the NCF does not seem to make this connection. It only links sustainability to the learning areas of humanities (Ministry for Education and Employment, 2012, p. 61) and education for democracy (Ministry for Education and Employment, 2012, p. 36). With regards to the relationship between schools and communities, the NCF recognizes the symbiotic relationship that these two can build – the community can be an asset for education to create contextualized and authentic learning experiences, while schools can be an asset for communities pursuing visions of lifelong learning and societal changes, and for preparing students for jobs that the future market will need. The school is also presented as a community of learners in the NCF while the same document also promotes collegiality between educators. Nevertheless, the aspect of community involvement in processes related to technology, such as the design process is absent.

The theme of 'Access and cost of technology' while being very present in the interviews, does not encompass a wide range of sub-themes and codes. Out of these sub-themes and codes, some do not and were not expected to appear in the NCF since they are rather specific. One of the codes that was however present is that of independent learners. Independent learning was mentioned several times in the NCF. A second code which appeared in the NCF was access to information. The NCF recognizes that in today's world, the "availability of and accessibility to different information sources enables children to engage with and make sense of the world around them…" (Ministry for Education and Employment, 2012, p. 49). The link to technology education is, however, not obvious.

The efforts made by the Ministry for Education and Employment to set up a framework for a national curriculum have resulted in a document which makes a valid attempt at imbuing students with the skills and values that are relevant in today's world. Where the NCF is lacking however, is in its narrow understanding of technology education.

Despite identifying Science and Technology as a learning area, the two fields are always discussed separately within the document. Moreover, when comparing the language used in relation to science to that used in relation to technology, it indicates a mature view to science education but a very narrow perspective of technology education. Technology education is still seen as a stand-alone subject which "primarily concerns 'design and make' tasks" (Ministry for Education and Employment, 2012, p. 35) and is inferior to, dependent on or applied science. Science and Technology are equal partners which contribute to each other – this is the view that should be made clear in the NCF. The ingredients for making the curriculum relevant to technology education are present within the NCF, however, they are not linked to technology education because of the narrow view towards technology.

Another interesting aspect of the bias towards science in the science and technology learning area is in the way the time allocated for science and technology is distributed throughout the learning cycles established by the NCF. The NCF establishes that in the junior years, 15% of the time should be dedicated to science and technology as a learning area. This figure goes down to 12.5% in the lower secondary and senior secondary years. It is worthwhile to mention that D&T in only compulsory in the lower secondary school years (Years 7 and 8) and can be chosen as an option subject in senior secondary school years (Years 9, 10 and 11). On the other hand, students always have a compulsory science component in their timetables throughout their education cycles. Is it to be assumed that science education is also covering the technology aspect that students should be receiving as part of their general education? Again, the idea that technology is just the application of science seems to be embraced by the NCF in this instance.

In his book, De Vries (2016) establishes that a good method for identifying whether a curriculum is appropriately representing a fair view of technology is to assess how well it embodies the different conceptualizations of technology established by Mitcham (1994). These are technology as artifacts, knowledge, processes and volition (Mitcham, 1994). The NCF does a fair job in conceptualizing technology as artifacts as it mentions the use of tools and materials in creating artifacts. The conceptualizing of technology as knowledge is however, lacking on many fronts as discussed earlier in relation to the 'Types of knowledge' theme. One could argue that only half the story is presented when it comes to conceptualizing technology as processes or actions in the NCF – although the design and make processes are mentioned, there is no mention of the aspects of using and maintaining objects which are an important part of conceptualizing technology as processes. The last conceptualization of technology is technology as volition. Once again, this is completely lacking as discussed earlier.

One last measure that De Vries (2016) suggests for determining the suitability of a curriculum for a proper conceptualization of technology is to look at the references to literature used in writing the document. In the case of the NCF, none of the references are specifically related to the philosophy of technology and therefore it would be difficult for the NCF to give an accurate, contemporary conceptualization of technology. Many of the sources used in the NCF are in fact related to early childhood education and none are related to any of the specific learning areas.

6 Conclusion

This research was motivated by the changing nature of the world around us, specifically, changes in technology, and the idea that despite this constant change, there are some underpinning commonalities such as the skills and values required to harness new technologies. The context of the Maltese education system was chosen to identify whether opportunities are present for learning these skills and values.

The research questions were formulated and a methodology for addressing them was devised. A literature review was carried out to identify the common features of new technologies as well as the skills and values required to harness them. This was then followed by semi-structured interviews with six key experts: two from industry, two from academia and two from the education sector. A thematic analysis was then carried out to identify themes from the interview transcripts. Eight themes were identified in total:

1. Access and cost of technology
2. Knowing your basics
3. Technology and communities
4. Cross-curricular learning
5. Constructivism
6. Mindsets (ways of thinking)
7. Types of knowledge
8. The digital nature of new technologies

The information from literature and the results of the thematic analysis made it possible to answer the research questions. With regards to new technologies, it was established that they are digital or supporting automation of processes, and to a lesser extent, related to or supporting a view to sustainability. A list of skills and values required to harness new technologies was compiled by using both literature and the thematic analysis (See Table 5). Finally, an analysis of the curriculum to establish whether opportunities for learning these skills and values are present was carried out. The curriculum was also analysed with regards to the other themes identified from the thematic analysis. The overall finding was that while the NCF presents many of the ingredients that are required for a sound conceptualization of technology, the links to technology education are not made due to the narrow view of technology that the NCF holds. This view sees technology as the application of science and as being composed principally of design and make activities. Thus, while the NCF presents opportunities for the conceptualization of technology as artifacts, it lacks, to differing degrees, in presenting opportunities for the conceptualization of technology as knowledge, processes and volition.

The results from this study are not free from assumptions or limitations. One of them being the recruitment of interviewees. An effort was made to recruit individuals who are as diverse as possible, the two academics were recruited from two different faculties of the University of Malta (UoM). However, that does not mean that careers and professions in technology are limited to graduates from these two faculties alone – there is an ever-increasing choice of degrees related to the STEM sector at the UoM (Azzopardi, et al., 2019). Neither does it mean that the only institution that offers the possibility to pursue further studies related to D&T is the UoM. The Malta College for Arts, Science and Technology (MCAST) and foreign universities and institutions are also an attractive choice (Loughborough University, 2022; Stanford University, 2022; TUDelft, 2022). Additionally, within the two faculties from which the two academics were recruited, there is a wide range of interests, perhaps the most obvious being the major streams of mechanical and electrical engineering or in the case of the Faculty for the Built Environment the major streams of architecture, and structural and civil engineering. It is important to point out that even within those streams, interests vary considerably and therefore the skills and values that are emphasized by people from different backgrounds may differ to some degree. A similar scenario applies to the professionals from industry.

Other limitations arise from the research tools used - both the semi-structured interview tool and the method of thematic analysis used for analysing the interview transcripts have their limitations which are discussed in Chapter 3.

The NCF is not the only document that makes up the Maltese curriculum. As a recommendation for future research, the other two documents that make up the curriculum, namely the Learning Outcomes Framework and the D&T syllabus should be analysed for the same skills, values and themes identified in this research.

Lastly, it is important to note that while the curriculum provides a framework for teaching and learning, there is a myriad of other factors that influence the success or failure of the implementation of a curriculum. Educators at all levels play a very important role in this regard as the orchestrators of experiences within the educational setting. If technology education is to be pursued as an essential part of general education, all educators should hold a common conceptualization of technology and be aware of contemporary views in the philosophy of technology. This can be achieved through continuous professional development courses about the matter. This is by no means an easy mission, but if the common goal of providing a sound, cross-curricular, technological education to students is to be achieved, a common understanding of technology must be held by all educators.

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Appendix A – Semi-Structured Interview Guide

Basic Information about the interview:

Date:

Time:

Location:

Interviewer:

Interviewee:

Introduction

Thank you for agreeing to do this interview. I am Mireille Attard, and I am currently reading for a Master's Degree in Teaching and Learning in the field of Design & Technology. Part of the requirements of this degree is a dissertation. The research I am conducting for this dissertation relates to opportunities for learning skills and values related to new technologies in Design & Technology in the Maltese secondary school curriculum. Design & Technology, often referred to as D&T, is a subject offered at secondary school level, in which students design and make artefacts. Through the processes of designing and making, they learn about the design process and start gaining some experience in the use of technologies. I am conducting these interviews to help establish what key experts, such as yourself, deem the common features of new technologies to be and, to determine what skills and values are required to harness new technologies.

The rationale of the study revolves around the fact that new technologies are emerging at very fast rates, and it is almost impossible for someone in industry to keep up with all of them. However, the underlying skills and values gained through experience with a technology could help one to become proficient in another technology more quickly.

I will begin by asking you questions relating to your academic and professional backgrounds, we will then progress on to the questions relating to new technologies and associated skills and values, their teaching and finally your views about technological knowledge in general.

The interview should take approximately one hour.

Do you have any questions for me at this point?

Questions

1. Can you describe your academic or formal training background to me? What qualifications you possess, any research you might have carried out and whether this influenced the choice for subsequent training.
2. Can you take me through your work experience or professional background?
3. We're now going to go into the part of the interview which relates to new technologies. Can you think of and mention technologies which you have either implemented, started using, suggested, or read about recently?
   If interviewee mentions examples of new technologies go to question 4A, if interviewee mentions more traditional technologies go to question 4B.

4. Choose between:
    a. How do these technologies contrast with more traditional ones – technologies which were either used in the past or have been used for a long time?
    b. Are there any reasons why new technologies are not being used?
5. Can you mention barriers to the implementation of new technologies?
6. Can you think of any common features of the new technologies (that you mentioned earlier)?
7. Can you think of underlying skills and values of new technologies which are either common or which may help one learn a new technology more quickly?
   If elaboration of what is meant by 'skills and values' is needed, consider using examples from the below:

Resilience	*Evaluation of new ideas*	*Problem-solving*
Capacity for change	*Pattern recognition*	*System approaches*
Constant development	*Self-learning*	*Project planning*
Collaboration	*Integrating and interconnecting knowledge*	*Quality assurance*
Critical thinking		*Optimization*

8. What would the best way of teaching these skills and values be?
   E.g., Behavioural, cognitive, constructivist, problem-based learning, project-based learning

9. What role does the teacher take in this method?

   E.g., Manager, supervisor, facilitator, model, motivator

10. Technological knowledge is made up of two components: conceptual knowledge and procedural knowledge. Or 'knowing that' and 'knowing how'. "Design, modelling, problem-solving, system approaches, project planning, quality assurance and optimisation are all candidates for technological procedural knowledge" (McCormick, 1997, p. 144).

    Do you think that one type of knowledge is more important than the other?

    Examples of conceptual knowledge: circuit theory, logic, laws of thermodynamics, laws of motion, material properties

11. Is there any further information that you would like to share that we have not covered?

Conclusion

Thank you for your time and for providing insightful responses to my questions – they will surely help my research. I will be sending you a copy of the transcript of the interview in due course, please do not hesitate to let me know if there is anything you would wish to add or remove from it.

Appendix B – Interview Transcripts

Academic within Faculty for the Built Environment at the University of Malta

Some parts of this interview transcript have been omitted to protect the identity of the interviewee. These parts were replaced with the words 'omitted text' enclosed in square brackets.

Interviewer: OK, so the first question; can you describe your academic or formal training background to me? What qualifications you possess and any research?

Interviewee: *[omitted text]*

Interviewer: So, in the realm of architecture, what do you mean exactly by computational thinking?

Interviewee: So, let's say 20 years ago, architecture was dominated by star architects. Zaha Hadid, Frank Gehry, like Bilbao Museum, you know, like aesthetics, iconic building, like star architecture and iconic building, and now the switch is more kind of grassroots level, bottom up. So, things like working with communities, working with participatory design, investigating material properties so materials would do what they're meant to do. So opposite of I want it like this, so let's make it out of reinforced concrete or steel, it's like no, let's see what timber wants to do, you know, kind of working with the properties of materials. In a way, in its thinking, it's almost kind of going back to vernacular in its thinking towards resources. So, aesthetics almost, not take a second place, but the aesthetics come out of a process. It's not "I want it to look like this", it's more like optimizing the form with the forces, optimizing the material to work with the properties of material, and then to a certain extent, buildings end up looking organic and curvilinear, but not because necessarily that was the intent, it's because that kind of emerged from the process. So, kind of my focus was on materiality but as I said, the same process could be developed with stakeholders not with, maybe the person, the client or the investor, but more with the community let's say.

[omitted text]

Interviewer: The next question in the interview now relates to new technologies; so, can you think of and mention technologies which you have either implemented, started using or maybe suggested or read about recently?

Interviewee: As I said, my work is mostly theoretical, but when it comes to kind of making it practical, it happens by teaming up with a colleague *[omitted text]* they're very focused on fabrication and rethinking materiality. So, we did an interesting project, *[omitted text]* we managed to pull off quite a sizeable pavilion with a desktop size CNC router. It was 90 by something, I don't remember. It was meant to be a prototyping machine that we kind of abused to be a full-blown CNC. But it was a nice thing doing everything in house and obviously we had to do a lot of tests. *[omitted text]*. It was a lot of kind of trial and error. The first one fell to bits and then we did it again and then optimizing the shape, the rotation. When it comes to technology, I can't say that I have exposure to cutting edge, but that wasn't even... It was always kind of this grassroots level; what can you do with some really affordable things? And then later on with him, every year we have a design study unit with the master students and then every year we kind of have a different theme. One year there was investigation into fiberglass, other times it was working with geometries and *[omitted text]* using laser cutters and CNC routers. Some students used 3D printing, but I personally am not that involved with that. So, as I said, my interest is mostly a theory and geometric side of things and then fabrication is his expertise. And obviously then when it comes to software, again, because my interest is geometry and resolving geometry, no evaluation softwares, it's simple, it's Rhino with Grasshopper I found most… And also, when I teach, I like to use Grasshopper because I focus as I said on computational thinking. I ask students to really understand the geometric logic of something they are developing, so once they fully understand, and we literally develop geometric logic as a step-by-step algorithm, you know, I start with… I don't know like a Polygon ABC, midpoint, maybe you know, connect… So, I tell them, develop an algorithm to the point where I follow line by line and I can actually, you know, develop that. Once we have that then we can use Grasshopper, you know, because quite often they get tangled up into using Grasshopper as a modelling tool, which it is not. It's modelling of logic or processes. So, this is where I kind of always… My focus is as I said, not aesthetics, not evaluation, but the process, design process itself and logic behind it.

Interviewer: So, you mentioned a few fabrication technologies like CNC routers, 3D printing, laser cutters and whatnot, and you also mentioned some software packages which seems to be more your, kind of, field. How would you say that these technologies contrast with more traditional ones? What did you used to do before you had Grasshopper and before you had Rhino?

Interviewee: I don't know how to say this, but I think what these tools… It's kind of computation work versus computerization. So previous digital tools like AutoCAD, it's really how you use them. So, if you're going to automate a process you can do by hand, I don't think that tools will give you much. So yes, I can draft by hand, and I can draft in AutoCAD. Obviously in AutoCAD it's easier because of the printing and editing and all that because I am that old that I used to draft by hand so I can appreciate the switch. But also, I think something is also lost, especially maybe when nowadays a lot of students remove sketching because this kind of connection between your thinking and your hand and the pen. Uhm, I don't think that smoothness in kind of when you're seeking ideas or trying to make your thinking come out on paper, I don't think mouse or AutoCAD is easy to capture that. This kind of… Still, kind of… let's say maybe some vague ideas or kind of. Uhm, I think AutoCAD is really useful for production of drawings, but not for the design development. So, I think I actually claim that certain tools are actually detrimental for creative thinking and design thinking because a lot of times, let's say, the moment I noticed in teaching where 3D tools, like SketchUp, that they're easy to learn, so before it was like Maya and 3DMax, very difficult to learn, the learning curve was very high, so building a model and developing the project through sketches and physical models was the way forward. But then you'll see you kind of work with the site, you understand the scale, you understand even… You work with the physical model, your working model, you understand the curvature, you understand the materiality, you understand gravity – that's probably the most important aspect. When you switch, let's say, curvature disappeared because SketchUp doesn't allow you to do curves. So, then what happens is what is considered as instrumental knowledge, the knowledge of the tool, caps your design skills. So, we still try to push students, especially in early years, to use, to develop physical models and then translate them into digital models that would help them build more. You know, it's a back-and-forth process. In that sense I think that using digital tools for computerization is not giving you anything for design process. Using digital tools for computation, for design process, for kind of modelling your logic, for testing your logic... So, if I'm model in Grasshopper, my computational, my geometric logic, then I can come up with options I didn't anticipate, right? So, I relate parameters and in my mind I kind of have, in a way they can play out, but obviously then in Grasshopper I can have probably some ridiculous unusable options, but sometimes some of those ridiculous ones kind of create this click, that's it. You know, kind of allow you to change the perspective in a way.

Interviewer: I understand. They might not be usable, but they might give you an inspiration to do something else, something more creative.

Interviewee: In a way, working with students, sometimes you get a solution from a perspective you would never think of. It's a valid point of view – it is absolutely, but I think my goodness, I would have never thought of this, and I think in a way, these kinds of ridiculous options open these doors where I'm like, wait a minute, it could be like this. So, then you go back, and you rethink your process and I think in that sense you move out of some kind of standard procedures you might develop, to kind of really further explore your process. So, in my thinking I distinguish between process, which is kind of modelling or how variables come together, and procedure which kind of is test, try and test. Sometimes obviously you need procedures, but it's all kind of in the design development. So, what was the question?

Interviewer: Well, I was asking about the contrast between new technologies and traditional ones.

Interviewee: Traditional so, I'm talking about architectural design, right? The power of working model of working with models – I'm not talking about representative models, but kind of very, maybe not necessarily nice-looking cardboard models that you will chop and re-chop and take photos and rethink and look at the shadows and probably they won't even survive, and then you know kind of like sketching volumetrically. I think those should be used more and I think their value will never disappear. And the fact that if I'm making something from paper, I automatically know it's a single curvature, automatically know it can be done from a sheet material like glass, like metal like you know, like I automatically have that building into that. So old tools and sketching, I don't think those would ever be lost. I think computerization, automation of things will always be there, but I don't think, as I said, it's bringing us more. And I think then, the challenge with new technologies is instrumental knowledge – knowing how to use software or digital tools or whatever, in a way where you are using them and the lack of knowledge of how to use them does not cap your ability to express yourself. So, the crux for me is not the tool itself, it's the instrumental knowledge to use that tool. Because as I said, if you only know how to use 3 commands in SketchUp, your architecture is going to suffer and if you shy away from any kind of, let's say curvature, I'm not arguing for curvature, but if you eliminate that geometry from your design process, just because you don't know how to draft it…

Interviewer: Yeah, obviously your design is going to suffer then.

Interviewee: Yes, yes.

Interviewer: And so, moving on now to the implementation of new technologies; can you think of any barriers that there might be to implementation of new technologies?

Interviewee: Instrumental knowledge.

Interviewer: Instrumental knowledge will be the big barrier.

Interviewee: Definitely, I mean, from what I understand, I can't cite anything on this, pure observation – we have digital tools available in Malta. Companies do have CNCs and where they struggle is to go beyond these, kind of, pre-set commands, so they kind of, you know… Where research excels abroad, in some hubs of research like ETH Zurich, is that they engage computer scientists to work with them and their role would really be to go behind the scenes and take control… In architecture it's kind of like Gibson's theory of affordance. Affordances are what something can do, so you know, a spoon is to eat soup but if you can also make it an affordance to, I don't know, paint with it, you know you're expanding, so the more we know the tools, that affordance grows. So, I think the exciting thing will be when eventually we get team up the craftsmen, the kind of the material knowledge, the traditional knowledge, from designers and architects and the computer scientists that will kind of unlock that barrier and allow also possibly even the traditional craftsman to engage and to transfer their knowledge into digital tools. I think digital tools have this amazing thing to allow collaboration, but there is this stumbling block of controlling them, not them controlling us.

Interviewer: I understand what you're saying. Can you think of any common features of new technologies then?

Interviewee: I wouldn't know… Steep learning curve…

Interviewer: OK, so maybe can you think of any skills which might help you… Let's say you know how to use one thing and you need to learn how to use another one… So, the question is, can you think of any common features of new technologies? So, you seem to be mentioning a lot for example that they are digital tools, so that would be a common feature. I think you said your interest basically, if I understand correctly, is digital tools really. So, the fact that they're digital then would be a common feature. Can you think of other common features?

Interviewee: I think possibly that the user requires this switch in thinking. Digital architecture is really kind of, as I said, possibly giving up of a very specific solution and allowing multiple variables to play out. Like the ability of the tool, the materiality – the design process becomes all these capacities and constraints coming together. I think that would be a common feature maybe. Again, I'm not talking about automating what we know, but allowing digital tools or new technology, to kind of expose new solutions or new opportunities. I think probably that is more something common for new technologies compared to old technologies, that if we have instrumental knowledge, and if we kind of allow the processes to happen, to play out, then certain outputs and variants we can allow them to happen and kind of learn something new instead of automating. I think with the old technologies it's a lot of automation of what we know.

Interviewer: My research is focused on underlying skills and values so the next question is, can you think of underlying skills and values of new technologies which are either common or which may help one learn a new technology more quickly? So here what I'm after is more general skills, or skills that can be generalized more.

Interviewee: I think this is possibly something I noticed, I think it's not me, it's written in the newspapers even, and I think necessity for analytical thinking and creative thinking so kind of, openness. So, I think if we think about design, the crux of design, is formulating the problem that we are designing for, and I think that possibly, with current education, it's a lot of kind of repeating what we see, and I think new technologies allow us to start from scratch that's why analytical thinking is necessary. What exactly am I addressing? So, it's not the question of like “OK, we need to design, I don't know, vacuum cleaner”. No. “We need to remove dust from this room”. So, you start really rethinking the problem and then contemporary technologies will allow you to test it on the level of software analysis. Just to kind of maybe put things into perspective, we encourage students a lot, especially at master’s level, to rethink everything, because we know that constructing building with the current materials is failing us. The way we construct is failing us. You know with climate change, with overdevelopment… Then you allow students to just go out there and then we talk… Let’s see, resources, Malta is very limited in resources and always was, and stone is running out and there is this argument on whatever stone is left – “we should keep it for the upkeep of all the built heritage that we have” and then it's like “what do we build with?” And then when you allow them to really start from scratch… Obviously kind of waste is the most abundant resource, so waste is just lack of affordance. It's like it's something we didn't find a use for, so there isn't such a thing as waste – it's our lack of ability to find the use, to make it useful. So, with that kind of thinking then obviously the new technology allows you to start thinking are we crushing? Casting? You know, then you know now I have CNC's now I have 3D printers, now I have all this so I can start imagining this new materiality. There was one student who said, well we have abundance of seawater, that's probably Malta’s most… and you say but this is mental... what do we do with this? We make salt blocks gel together with… I know it's theory, I know, it's far out, but sometimes maybe with this climate change, which is obviously going to be severe, maybe we do need that level of rethinking everything and then his theoretical argument was we make salt blocks and bind it together with seaweed gel. So, I think in that sense you can then rely on that problem being solved with the new technologies. Recently a student (she did bachelors here, she's doing her masters abroad) found a statistic that for every stone cut, like 1/4 is lost in dust and then she said “what resources are abundant in Malta? It’s waste, it's salt, it's dust”. I mean Malta is famous for its dust and then she said “OK, what if we can harvest? What if we kind of can capture it?” And I think contemporary technologies allow you to go that far out, but at one point you say, “is it far out?”, you know like everybody in Malta has allergies and you know... And now we have more dust with the demolition and everything and as I said, contemporary materials are failing us, and they're very CO_2 intensive, and this is already out there, and then you start thinking, but it makes sense, and I think digital tools, or technologies in general, allow us to pursue maybe these possibly crazy dreams which maybe become valid.

Interviewer: They could help us make them real right? What sounds a bit like a crazy idea…

Interviewee: Well, but to arrive there you need analytical thinking, you really need to be open to say, "what are the resources in Malta?" You really need to be open to everything and then creative thinking to say, "and what do I do?" Once I formulated this problem, how do I then follow it through? Otherwise, we'll end up with computerization and automation of something we know is obsolete and I think COVID even more showed us how just the way we live, the way we work, even the way this interview is conducted – three years ago, we would have had to meet, we would never consider this, but it's obviously working. The user is in control. That's why I say it's a tool because it is...

Interviewer: It is at our service.

Interviewee: Yes, there is an author who said that we are, sometimes it's a bit of a harsh word, but subservience to technology and it should be other way around.

Interviewer: The next question is about teaching, because obviously my masters is a master's in teaching and learning. What would the best way of teaching these skills and values be? So, this analytical thinking, what's the best way of teaching it?

Interviewee: Well, I don't know… Which age are you talking about?

Interviewer: Well, in my case secondary school, but if obviously, your experience is with tertiary…

Interviewee: No, but I think from what I understood, secondary school it's where there is this kind of drilling towards the exams. I think in secondary still, it's really allowing children, young adults right, to truly kind of express themselves and not ask them to kind of repeat what they see around them, but really allowing them, almost maybe mixing it with arts or with maths and then they make a video game… They make something you know; they wouldn't even know what they're doing. I mean I know my son is coding in Minecraft, he was a kid of seven years old, he just set up a for loop for 800 sheep and I said, you know how much time I spend to explain a for loop to students? But in his case, because it's hilarious, you make hundreds of sheep, ha ha ha… You know, there it is, he's done it, and he types, for I =, you know… So, I think if we teach, let's say, maths and physics, or allow knowledge from maths and physics to be applied in video games, carnival floats… I think then it's something fun.

Interviewer: Drawing on the students' interests, yes, and learning maybe different subjects together.

Interviewee: Generative art is such an easy to produce, it's so fun to kind of play out these beautiful images and video editing. I think if they are really tapped into their passion, making music, and then the technology becomes not something you learn at school, but something that you really kind of make it work for you. Almost like Montessori kind of thing. I mean when I was teaching this kind of computational thinking one of the students was actually playing for the national football team and he obviously decided to design a football stadium, optimizing the size. This is something he was interested in and obviously then it was done with passion. Another student developed a video game. One, we're reading a text of Italo Calvino invisible cities, and they illustrated it in Grasshopper. They developed this dreamlike work. Now with 3D printing you can print jewellery; you can print clothes… As I said I didn't study here, but as I understand, maybe this system of knowledge (I think is the subject), allowing them to really, really pursue something, and nothing is ridiculous, you know what I mean?

Interviewer: Yes, yes, not shooting down any ideas.

Interviewee: No, no, I mean if they could be making skateboards and Christmas ornaments and theatre plays, you know, everything. Then when you're driven by passion, then they will make technology work for them.

Interviewer: And what's the role of the teacher in all this? In your opinion obviously.

Interviewee: I think asking them not to settle to what they know, not to repeat what's around and really pushing the analytical thinking, asking them questions to really understand what exactly they are doing. So, as I said, you're not making a specific object, but you're addressing a certain need or set of problems, so really kind of understanding what their needs and problem is and how to how to address it, not in the ways that it's already done, but in the way that really is suitable for what they're talking about.

Interviewer: Very good. And now the last question is a bit more generic. It’s about technological knowledge. A lot of authors actually have described technological knowledge as being made up of two components. And usually, it's conceptual knowledge and procedural knowledge, or ‘knowing that’ and ‘knowing how’. Some examples of conceptual knowledge would be the laws of motion or material properties. And procedural knowledge then would be design, modelling, problem-solving. Do you think that one type of knowledge is more important than the other?

Interviewee: Let's say in architecture it's kind of touching a little bit on this affordance. It's, let's say, knowing what material can do, but also knowing how to engage it. I think it's something that works in parallel, and I think with every design process, if it's not, as I said, computerized, but it's a true design, with every cycle, because design is a lot of iteration, right? Go back. With every cycle you kind of gain, let's say, if you're doing material investigation and maybe bending something, now I know what material will do, but what will, let's say, the machine itself allow me to do? Now I know more about the material, more about machine. How do I marry one to the other? So, I think it kind of forms this circular loop. I would put them all under the umbrella of design knowledge, both of them. So, the design knowledge grows with every iteration and that's why I think design should be both sketching on paper and prototyping on working models. Kind of, it needs to come out. Then maybe comes, you know, digital modelling and evaluation. And then it comes out and it's tested. And then it's probably going to fail. Now we know, and then we go again. So, I think it's an iterative process, but they feed off each other.

Interviewer: That's very interesting. I like the idea of parallel – it's a very good way of looking at it. Is there any other…?

Interviewee: No, but I think that is where we, especially in architecture, we're suffering, right? We have amazing master masons who are also disappearing, and they have knowledge of stones and stone is it's not, uh, it's different. So, from what I heard, like they kind of can knock on the stone and tell you, and touch its dust and tell you, oh, this is good for the foundation. There is kind of this tacit knowledge, knowledge that you don't learn through books. But then because of lack of technology, then they become limited to traditional tools and somehow, I think then, this kind of, as you said, know how, lack of knowledge, then there's a loss in a way. Then maybe architects know how to use certain technologies but don't have that tacit knowledge of the material. That's why I think it's a lot of investigation and research, which obviously we don't have enough in Malta, especially for architecture Through this process we all kind of learn and then the technology allows us that collaboration and that sharing of knowledge. It's kind of a platform.

Interviewer: OK, OK, so that was the last question basically, thank you for your time.

Interviewee: I felt like possibly I confused you more. So, if you start transcribing this and just…

Interviewer: Oh no, it's very interesting to get a different perspective because I'm an engineer and I think in a certain way so it's nice to hear a perspective from someone who comes from the side of architecture. I feel it is more creative. Engineering somehow can be a bit more rigid.

Interviewee: But yeah, but that's why I believe in teamwork you know. I think you need, as I said, crazy architects and then engineers to kind of shake... We need engineers to help us do all this. So, I think it's definitely a symbiosis.

Interviewer: Yes, yes very much so. Thank you. I will be transcribing this obviously as you said, and I will send you a copy of the transcript. If there's anything which may be misinterpreted obviously do let me know. I amend. Obviously, I wouldn't want to misinterpret anything. Thanks again for your time, I really appreciate.

Interviewee: Good luck.

Academic within Faculty of Engineering at the University of Malta

Some parts of this interview transcript have been omitted to protect the identity of the interviewee. These parts were replaced with the words 'omitted text' enclosed in square brackets.

Interviewer: First question, can you describe your academic or formal training background to me? What qualifications you possess and research that you might have carried out, whether this has influenced the choice for subsequent training and so on.

Interviewee: *[omitted text]*

Interviewer: *[omitted text]*. Can you think of and mention technologies which you have either implemented, started using, suggested or read about recently?

Interviewee: *[omitted text].* We're developing IoT or IIOT – Industrial Internet of Things, so objects and machines which are connected and networked to each other. So, network engineering, for example, and network technologies, start to play a very, very important role. They are a little bit of the underlying foundation for more or less everything else because then, on top of that, I have decided to more or less stick to two technologies, so that is the underlying – the networking, connectivity issues, and then I'm building on two areas; one of them is collaborative robotics, cobots. So, robots in the same environment as humans, so without guards, without the need for having any stops, let's put it this way, when humans come into close contact with them. So obviously with that then comes the smart aspect, so AI and internet of things like vision, machine vision systems to recognise humans, objects and everything in between. So, the idea is that we're bridging these systems in order to develop the workspaces of the future. Intelligent, smart workspaces where humans and computers and machines work all together. When we look at that as well, we've also been working on intelligent systems from a machine learning point of view, once you've connected everything, once you have access to all of your machines, you also have access to a lot of data, a lot of information. So basically, you have big data and anything which you can analyse and extract from that big data from the machines which you have over there. Obviously, “what skills do you require in order to get here?” is a little bit of a very wide discussion. Obviously, there are the digital skills underpinning all of this. There is programming – so you need to have the programming skills in order to actually write the machine vision, algorithms, machine learning algorithms to control algorithms for the machines and all of those aspects. Networking, as I mentioned. So, the skill of being able to set up a computer network in order to connect objects with respect to each other. Then you have the fabrication side as well. Let's say that there are two aspects to fabrication which we find quite cross cutting because having the skills more or less opens a very large breadth of opportunities. The first one is 3D printing. 3D printing is very important because we use it for prototyping, yes, but we use it even to build machine components. Any automation component, unless it is structural and requires to be built out of aluminium or steel, etc. 3D printing opens up a wide array of opportunities, so 3D printing is very, very important. And then the other one is machining and CNC machining specifically. CNC machining in itself is quite a wide array because you can have a laser, you can have a waterjet cutter, you can have a milling machine, you can have a lathe, so I'm not speaking about the process per se, the manufacturing process, but rather how machines are controlled and obviously the opportunities that come with them. If we start going down that route, you need another basic skill which is CAD. So basically, we need to model the systems which we design, and from a 3-dimensional perspective obviously at the modelling done in CAD.

Interviewer: And I think CAD will intersect with both 3D printing and CNC milling.

Interviewee: Exactly, so that is a little bit like networking being the fundamental for IoT and all the rest. CAD is a little bit the fundamental for 3D printing and fabrication. Anything along those lines.

Interviewer: OK, and how would you say that these technologies contrast with more traditional ones? So, technologies which were either used in the past or have been used for a long time.

Interviewee: Let's start from the later part when I was mentioning 3D printing and machining. Over there, most prototyping work, and even machine work, previously was manual, so you needed to have the manual skills to operate those machines and the manual way. It doesn't mean that we've automated completely the fabrication, and it doesn't necessarily mean that you don't need to have the skills and knowledge to operate those machines. Maybe not manually because you're not driving as used to done before with the wheels and you’re driving the manual carriage, but the actual machining knowledge still needs to be there. You need to know what cutters need to be used. You need to know which feeds, the depth of cuts and everything. The software doesn't automate everything for you, so whilst the machines are controlled more digitally, you still need to have the knowledge of the process then which supplements that. Obviously, in terms of skills, certain things like the ways in which parts used to be aligned before, there used to be a lot of skill to just set up the part onto the bed, to make sure there is very good alignment, etc. With the use of certain technologies that reduces because that type of manual intervention has been automated, so you have measuring vision systems, you have calibration systems between the machines themselves, which allow the machines to calibrate themselves automatically and therefore you don't need that memory interaction so much. So that's one aspect. Obviously from the control aspect then, the digital side, this is a little bit more of a grey zone I would say, because really and truly, networking is networking. There's no difference in the way we network things today. Let's say from 1992, from Internet to now, it's the same Internet, it's the same IP configurations and everything.

Interviewer: Exactly. Networking in itself, you could say, is a new technology as well.

Interviewee: Exactly, so from that aspect it's a little bit strange to consider before or after.

Interviewer: It hasn't been around long enough, sort of. Maybe there were a few new protocols that came up.

Interviewee: Exactly, which most of the time, in our case, I won't say are transparent because they're not, but it's very detailed level work then. On the other hand, again with AI and computer vision – any form of programming – the programming languages change or adapt. Even the simulation tools which we have available, the programming tools which we have available, the languages which we utilise, change, but at the end of the day, how you program doesn't change.

Interviewer: Alright, so there's a sort of way of thinking that you need to acquire, that would help you then.

Interviewee: Yes, this gives you portability. So, I used to learn basic 23 or 24 years ago. The basic programming language. It doesn't exist any longer but what I learned over there in terms of setting up variables and loops, and if then statements, etc. What I learned there is portable throughout.

Interviewer: Exactly, and it's exactly that kind of skill that I am seeking to identify, sort of, in this dissertation.

Interviewee: If anything, what's improved is the access to that. 23-24 years ago, we did programming. How did we do programming? We wrote it down on the paper because we didn't have access to PCs. We didn't have PCs other than in the computer lab at school and the personal computer era was just about starting. I speak about the mid 90s. So, we had to learn it in that way. Nowadays, with an Arduino or a Raspberry Pi, the world is the limit – quite literally the world is the limit. The sensors which you can have, the programming which you can do, the interface and then everything else at entry level prices.

Interviewer: €40

Interviewee: Exactly, you buy a kit, and you can experiment and play around as much as you'd like. So, in terms of then learning – the learning aspect of that, to a degree is, not facilitated, but there's more access. Things that have changed... Again, if I look at the past 25 years, I wouldn't say a lot has changed. It has, but it's more from an accessibility point of view – access to those technologies rather than to the technologies themselves.

Interviewer: You mentioned 3D printing as well for example. 3D printing has been around…

Interviewee: Yes, it has been around for 25/30 years. The first 3D printer in Malta was here in 1991 or 1992 actually. The way that you would prepare a CAD model for 3D printing now compared to then is absolutely the same, but the CAD tools have improved – more user friendly. The simulation tools and CAM tools which go with these machines have improved drastically. Before you needed to be an expert in order to have access to these. Nowadays. I'm not saying I'm not an expert, but it's a very simple thing. At the back of my office there, you have the 3D printer and it's as simple as having it located in my office and there you go, you get the material, you set the thing up and you're printing with very little difficulties.

Interviewer: Yeah, but it's good enough. It's more than good enough. It's quite good actually.

Interviewee: Aha, and the results which you get are already very good.

Interviewer: Yes, and probably with the advent of other materials that can be 3D printed… Now, they're talking about metals being 3D printed, that will open up…

Interviewee: Obviously, we have the titanium 3D printer over here but really and truly once you learn the basics of 3D printing it's the process that changes and we have to learn the advantages and disadvantages of that process and all the nitty gritty of that process but at the end of the day, if you have a support structure for 3D printing, it's a support structure for 3D printing. If you're doing it for plastic parts or metallic parts…

Interviewer: Very little changes sort of. OK, very good. So, I'll move on to the next question now. Can you mention barriers to the implementation of new technologies? I think you've already hinted at it when you mentioned accessibility.

Interviewee: Aha, so, accessibility improved in my opinion, so accessibility to technologies has improved significantly at least in most areas. There are some areas where it's still a little bit difficult. If I would say something, it's the knowledge and the skills which there aren't. Those are the barriers, the main barriers, which I see. The skills and the knowledge of the people who, to a degree, have to teach these things. Starting from myself – I have to continuously remain updated and catch up with the latest technologies, the latest programming language, constantly to remain at the cutting edge in order to be teaching and training with the latest skills and knowledge. I've just updated last year my AI module and we changed everything to Python. I had to learn Python first myself before I could teach it then to the students, so you always have this little bit of, uh, not lost momentum… It's one thing training the skills of the students. You cannot even write training the skills of the trainers (the teachers) who are involved in that knowledge elsewhere because technologies change, the accessibility to technologies change, and again, we know because we do it, the accessibility and the possibilities which I mentioned which transpo require, for example, are phenomenal what you can do, but not everybody knows about that and that is the first drawback. Are there certain technologies which are still overly expensive? Let's say that as I said, for example, with 3D printing, not so much. If you go to things like laser again, even just having an entry level with €400, you can start off with, same thing with the benchtop CNC machine. So, this type of benchtop equipment has improved greatly the accessibility of these type of instruments. On the other hand, if you want to go for a robot, then you're stepping up and over there, there is still, yes, quite a bit, because now we're not speaking about a few €100 anymore, but we speak about thousands of Euros and obviously that reduces a little bit because in terms of digital tools per se, even in terms of, for example, open source software, simulation software and 3D printing software, CAM software, there's a much greater availability of those types of tools so unless you're going for something which is a little bit more… Again, I'm speaking about robotics again, industrial robotics, if you get an entry-level like Lego, even that type, you still can do it with under €1000, and you can teach some of the principles of robotics over there as well with less than €1000 budget. Over there, it's a little bit easier, but in reality, I would still stick to the skills and knowledge of the trainer – that's still probably one of the biggest barriers.

Interviewer: OK, I'm starting to encounter that as well. We just had our teaching practice and schools nowadays are very well-equipped.

Interviewee: But then, are there trainers who know how to use that equipment?

Interviewer: Exactly, I myself obviously don’t know how to use all the equipment that there is because there is so much and, you know, I have to dedicate time and effort to learn how to use those machines before I can teach that to students, and you need a level of confidence which is slightly higher.

Interviewee: Exactly, you have to be one step ahead of every question and every problem and every issue, so the depth of knowledge needs to be quite deep.

Interviewer: OK, so that was question 5. Question 6, can you think of any common features of the new technologies that you mentioned earlier?

Interviewee: The digital trend is across the board. On the other hand, this is important, we're not speaking about ICT here. So, this is the application of ICT to design and technology. For me there is a difference. Using digital technologies within design and technology is different from developing digital technologies or learning ICT because here yes, we're using digital tools, but we're using digital tools, we're not developing digital tools and there's an actual step. And if anything, that step should be utilised because this is a very easy way of how to entice students to develop a liking for the digital skills which are required because you're not just doing a computer programme which is a static program…

Interviewer: Aha, which you run in a virtual environment.

Interviewee: No, you're running it on something which is real, and something which they can perceive and something which they can see.

Interviewer: Tangible.

Interviewee: Exactly, that makes a difference.

Interviewer: Now when it comes to the underlying skills and values of new technologies, which are either common or which may help one learn a new technology more quickly. You've already mentioned the bit already, I know it.

Interviewee: Yes, but I’ve only gone over a few but I need to ask you to clarify what you mean by values.

Interviewer: OK, so that's a bit difficult to explain; so, some items are very clearly skills.

Interviewee: OK, like a programming skill is clearly a programming skill.

Interviewer: Exactly, that for sure is a skill.

Interviewee: Thinking is still a skill.

Interviewer: Yes, ok, but then there are other things, for example, such as resilience, that's more of a value than it is a skill, you know.

Interviewee: Digital programming skills are underlying throughout. For me, even the formation of an engineer nowadays, you need to have a lot of that type of knowledge. Hand in hand with those, as I said, is networking. For me that is an underlying and fundamental skill. The knowledge of how to connect objects to each other via the Internet via any other protocol, etc. – communication. From maybe a value, the understanding and the didactic knowledge of communications is very, very important, and to know what needs to be communicated and really understand the difficulties and the issues which are encountered in communications, etc. That is underlying. I would say, AI is a skill, especially at secondary level. That is something that can be developed in future years. Right? On the other hand, understanding the ways that humans interact with machines, there's a value which is very, very, very important. A lot of the work we do is as well, in terms of user interfaces. To understand really how you are communicating and passing information to machines, be it through a control panel, be it through a PC, be it through voice, be it through gestures, etc. I'm thinking of those small, tiny robots for example, they are all things that can be taught and explained even at that level in their basic principles at that age.

Interviewer: What about more, more generic, uh, things which are maybe not…

Interviewee: Modelling. Let, me try to explain modelling. 3 dimensionality. Perception of objects in three dimensions, right? I think that is one of the fundamental things. This, I think if we're going to go into fabrication, then you need to have that perception. You have to understand how an object… The relationship of that object with other objects, the construction of that object, the features within that object, so that object is made up of various features that can be, obviously manufactured in different ways. But the fact that you can perceive that object in three dimensions is fundamental. That leaves the door then, to CAD which leaves the door to 3D printing, to laser, etc. So, for me, that underlying skill, the capability of perceiving an object, not just by seeing, but by thinking of the objects in three dimensions and actually finding a way of how to transmit that, in fact, I'm a big believer in technical drawing for example, and technical drawing is one of the skills which allows you to develop that thinking, we still teach technical drawing to our first years. We have CAD systems. Do we actually do technical drawing in real life and in industry? No, no one goes and gets a drawing board and stays drawing, we have a CAD system to do that. It speeds up everything. But the thought process which is required to understand that object in three dimensions over there is fundamental, and we teach it through the technical drawing. For me that is still an essential skill, even though we have the CAD tools, the CAD software. Can they bypass that? I don't know. Principles of that levels of pedagogy may be beyond my knowledge and my skills. For me it's still very important that people can communicate using drawings and understand drawings, see an image of an object and understand how that object is going to look like in reality in three dimensions.

Interviewer: Seeing something on a flat piece of paper and being able to imagine it.

Interviewee: And reverse it, picturing it in three dimensions and being capable then, to replicate it in two. In terms of communications that for me stays.

Interviewer: Alright, anything else which, I don't know, any other skills or values I'm being a bit annoying about this question, but it's one of the questions where I where I'm trying to get the most information from, you know.

Interviewee: To understand things like sensors, data collection, data, the perception of data, right, how we understand data, how do we collect data… And obviously the analytical mind to look at problem-solving – given a problem and you can actually tackle that problem. The fundamental skills of an engineer. For me, design and technology is meant to lead towards the engineering. It's meant to prepare mentally, that engineer to start to think analytically, sequentially, in a well-ordered manner, scientifically, to a degree – you have a procedure, you have a process which you have… you are capable of following like an experiment to a degree, which is going to lead you somewhere. But that is why as well the problem-solving – you're given a problem, you're given a task, and you have to critically think how we're going to solve that problem. I potentially would go one step further, but it is my dream at the end of the day for our education system, that instead of going for closed ended problems, we start to go for open ended problems. So not problems that have one solution and if you don't get that solution, it's wrong, but rather the capability of dealing with open ended problems. Open ended problems that do not have one solution but many different solutions – you have to try to choose the best one, but it doesn't mean that because you didn't choose the best one it's the wrong answer. Dealing with that is still very, very challenging. Now from our students, listen, this is the problem, OK, assignment – Sir, is this good? Don't ask me.

Interviewer: Especially in especially in design tasks, there isn't really…

Interviewee: There isn't really, how do you confirm if this is good or bad? I mean OK, there is a sequence, there is the evaluation aspect and even that is important that we learn that listen, once you develop something, you have to test it to make sure that it conforms with your requirements. That is the basic process, but it doesn't mean that what you design is not good. There may be a better solution, but it doesn't mean that what you've designed is not good, and they have to deal with that. At the moment they don't, at the moment they think that there is one solution. Why? Well, because everything that we've been trained, if it's maths there is only one solution, if it's physics, it's one solution, if it's chemistry, it is one solution. If it is technical drawing, it is one solution. It is the solution which you find at the back of the textbook or in the teacher's training book. For students to be able to go beyond that and say, 'Ah, this is a problem' and in reality, real life problems are those problems. Very rarely is it the problem, which is the opposite one, the close, and where there's only one answer.

Interviewer: Yes, that that's very true. What you say is very, very true. The next question. What would the best way of teaching these skills then be? These skills and values, basically.

Interviewee: I would go, in this case, as in applied? It's not, but I always either get the nomenclature wrong...

Interviewer: OK, don't worry, I'll help you.

Interviewee: The fact that you can try something out over here is essential.

Interviewer: So, the hands-on, kind of…

Interviewee: Aha, but that is where it gets dangerous in people's perception. Most people, when you tell them hands-on, they think that they're actually, I don't know, cutting metal, actually welding things, actually... No. It is what I am meaning is you'll give them a problem and they have to solve it. That aspect of hands-on.

Interviewer: Right, I think I've read somewhere that that's a minds on approach.

Interviewee: Aha, minds on approach, could be…

Interviewer: You don't really have to make something...

Interviewee: You can do, you can make, but that is not the focus. The focus is how you are approaching that problem. That is the essential part.

Interviewer: OK, very good. And what role does the teacher therefore take in this approach?

Interviewee: That's why then, because the teacher becomes instrumental in leading because then the teacher leads, not instructs, because the second you instruct you have one solution. The second you say you have to do ABC. Nobody will do D or E or think about Z. The teacher has to lead, “listen, you need to achieve this”. How? Think, be critical, explore.

Interviewer: So, would you say that the teacher therefore is more like a guide?

Interviewee: Like a guide, a mentor. The teachers at that age, to a degree, are important to knowledge because at that age you still need the teacher as the portal to knowledge and “how am I going to do this?” in basic terms, but then on a higher level, the teacher is the person that communicates and guides and shows the path but doesn't plot the path. You tell them, “Listen, this is your goal. This is your objective. This is where you have to get to”. Just start from something small and then you build on that. You can't expect to give them a big problem and immediately, from day one, they're going to get there. Slowly, little by little, they need to be nurtured to be critical, to think. That is the single, most problematic aspect I think, which we have in our whole education system. We are not instructed to think, we are instructed to give that one answer: the right the correct. Which is the correct answer? That is, when we think about it… OK, what do they want from me? So, what is the correct answer? I need to provide that answer. It is not really the training which you require to coach your brain to be innovative, to think critically, to think outside of the box. Critical thinking and innovation. Thinking hats and creativity. Those become essential at that point in time because in real life it's impossible… I'm constantly learning to learn. I have to learn how to learn so that when a new technology comes up or when a new development comes up, I can face that and say, listen, in order to do this I need to learn this, this, this and this and I don't let anything stop me and say, “oh, because I don't know that, I don't know this solution, uh oh!” and panic, deer in the headlights syndrome. It is the first thing which we try to break out of our students. We do it through the projects, through the engineering project, through the final year projects, through the group assignments, etc. To break that feeling. Listen, this is an open based problem, solve it. To solve it? Do you have all the knowledge? It's not interesting for me that you have all the knowledge or not. If you don't have it, go learn it.

At that age the teacher has to act as that portal. The teachers who's leading and saying, "listen, this is the knowledge which you are going to need". But not in detail applying it and so on.

Interviewer: OK, so last question; a lot of writers agree that technological knowledge is made up of two components; conceptual knowledge and procedural knowledge. So, 'knowing that' and 'knowing how'. McCormick, for example, I don't know if you're familiar, mentioned a few examples of procedural knowledge such as design, modelling, problem-solving, system approaches, and so on. And there are obviously examples of conceptual knowledge, such as for example, the laws of thermodynamics, the laws of motion, material properties. Do you think that one type of knowledge is more important than the other?

Interviewee: That's a nice trick question.

Interviewer: There's no right or wrong answer here.

Interviewee: I know, I know, I know. And the answer is that to a degree you need both. It's tricky for the simple reason that, yes, I would tell you that procedural is at a deeper level, more important. There's formative… There is a formation over there, which is ingrained. You learn that all the time. Anything that you do. Theoretically, even preparing a shopping list, you can tackle a shopping list in the same way. But the know-how knowledge is different and that is continuously changing. It changes with technologies, it changes with application, it changes with fields, etc. Do need some basic principles and skills of that knowledge? Yes, it helps. I think it's more like, you should be capable of knowing where to access that knowledge, which is nearly more important. And that you have the capability of knowing that you can learn that at any point in time. Networking, I went 3/4 years ago – we were starting to set our IoT systems, etc., for me, networking was driving the PC at best, and connecting either to Wi-Fi or via cable to a router. I had no idea what the internet protocol or the IP protocol… That's where I got to, but I had to learn then because I realised that, if we're going to go down this route, I need that knowledge. And therefore, because I have been trained and I'm still doing it, then, I go out there and I learn about trying myself. I have my own skill set – personal skill set – which has been developed over so many years which helps me to do that as fast as possible. Is there some of it which is essential? I think you could say that there is some of it which you really require from a design and technology point of view. As I said, that aspect, for example, of knowing how to communicate in two dimensions, 3 dimensions etc. That is a bit of an underlying skill and knowledge which really needs to be developed and learned. But then it's more about applying it. I mean I have these two aspects… Can you do the problem-solving without having the knowledge? It's dangerous.

Interviewer: You probably end up not solving much.

Interviewee: Then, if you know what you have to look for, what you have to learn, how you have to learn it, etc., that knowledge, today, even more than yesterday, and I think rather more than a technological innovation, one of the biggest innovations which you have especially in this field, is the access to information. Nowadays through YouTube, through the various learning foundations etc., tutorials which you find, Autodesk, for example themselves have so many tutorials and things... If you want to learn something, it's there.

Go in there and learn it once you know that you require that knowledge, the knowledge is there, it's how to access it, etc. And then the beginning, you need somebody to guide you, to build that up, the first building blocks, but then, if you have the motivation to do it, as I said, the sky is the limit. So, every time sometimes I go into Amazon, and I start searching for Raspberry Pi, kids, etc. I'm really jealous of this generation. Absolutely jealous of this generation because we had nothing close to this. What we had to do was long, base board development. And it has its advantages because we weren't crazy.

Interviewer: I see it in myself sometimes… I mean, I was born in 1990 so you know… But still, going to the library to find a book has become an ordeal for me. Everything is so easily available on the Internet, you know?

Interviewee: I mean first years in the first four or five years that I was at university, I used to actually go to the library, get the book… I haven't gone to the library in years now. I find everything on the Internet. The library is just a study space.

Interviewer: Exactly, there's somewhere quiet.

Interviewee: It's not an access to knowledge and access to information. And that has its own negatives as well because… That thirst, that drive for knowledge.

Interviewer: Alright, so that was it in terms of the questions that I had. Is there anything maybe that you'd like to add?

Interviewee: From our end, this is a discussion which often, to a degree comes up, and it's a discussion which is a little bit controversial in here as well. I don't know if you saw the position paper which we published in the Times of Malta a week or two ago on critical thinking sciences, etc.

Interviewer: No, I haven't.

Interviewee: It doesn't mean that because we encourage critical thinking, the critical aspect, the scientific and science thinking we don't encourage the arts, the open thinking or creativity. On the contrary, for me they are one and the same. We can't have one without the other. They're both very important to form the engineer of the future. The technologist of the future.

Interviewer: The holistic part…

Interviewee: Exactly. So, I really wish you luck. I really wish that your work is well received and does impact our educational system because we really, really need to drive in this direction.

Interviewer: Thank you. I hope so.

Interviewee: This direction is very important for our country if we want to advance, to take this up. In terms of motivation, you should have a million percent of motivation because for me this work is really essential.

Interviewer: Thank you. Thank you for your time and thank you for your responses – they were… you hit the spot.

Interviewee: I'm happy that it's useful.

Interviewer: I will be sending you a copy of the transcript when I eventually get around to transcribing it. Obviously once I send it, if there's anything that you would like me to amend, just let me know. Thank you.

Interviewee: I really wish you luck with your work and that you actually manage to achieve or push a particular direction. It would be great to see this.

Industry Professional with Structural Engineering Background

Some parts of this interview transcript have been omitted to protect the identity of the interviewee. These parts were replaced with the words 'omitted text' enclosed in square brackets.

Interviewer: Can you describe your academic or formal training background to me? What qualifications you possess, any research you might have carried out, and whether this influenced the choice for subsequent training.

Interviewee: So, I'm an architect and civil engineer by profession *[omitted text]*, it was a five-year course, I chose the structural stream so the first and second years were generic and then in my 3rd, 4th and 5th I had to choose a stream. I chose the structural stream as opposed to the architectural or landscape stream. My thesis studies were related to recycled stone, so my background… I'm more into the sustainable side as well, aside from structures. We studied how we could actually reuse construction and demolition waste on the Maltese islands and then that opened up other opportunities because, I got into, am still looking into LEED certification and BREAM certification. It's an ongoing process. I've been working for the past 8-9 years now as a structural engineer more than anything, but I also do architectural design. That's my background in general. I worked in a private firm for seven years, and now I have my own private company where we offer all the services I just mentioned.

Interviewer: OK, so that also covered my next question which would have been, can you take me through your professional work experience? Which you've already mentioned. So, the next question then is about new technologies. Can you think of and mention technologies which you have either implemented, started using, suggested or read about recently?

Interviewee: I think in our case, in the structural engineering stream, one of the fundamental priorities is to know your basics. So before ever learning any new technology, you need to know what you're actually inputting into any new program that might be available. And I think once you know the basics of how structures work it will then be easier to implement onto any program. New technologies we use in terms of when we look into the computer analysis design and detailing programs, basically I would mention Robot mainly, or Microstran, which are two programs we use a lot. However, given that most of our projects are quite basic here locally we tend to use more of a simple excel sheet which gives us our answers. So, for basic slabs and beams we opt for structural calculations stemming out of the Excel sheet itself. For more complicated structures then, we opt for the other programs. Then there's other design programs which I feel are fundamental, like Photoshop, like SketchUp, which help us communicate better with the client and help us give a better visual to what we're trying to design or give back to the client. I would mention also Lumeon as a program which is a very good, animated program and it gives you like a very good, realistic, visual of what your project might look like and then there's ACAD. ACAD is like, it's a relatively old, let's say old, program. I wouldn't say it's a new technology, but it's an ever-growing technology. I mean they went into Revit itself, so ACAD is now maybe eventually phasing out and hopefully we'll opt just for Revit eventually, but I still feel it's a very important technology to date.

Interviewer: You could say it sort of evolved with the time.

Interviewee: It's evolving, exactly.

Interviewer: And so, how do these technologies which you are mentioning contrast with more traditional ones. So, with technologies which were either used in the past or have been used for a long time. So, for example you mentioned CAD, before they used to draw with pen and paper, you know, directly on a drawing board. Can you think of more examples of how older technologies contrast with new ones?

Interviewee: Yes. So, there's the drafting side, which obviously helps in being much more efficient I must say. And if we were to compare ACAD with Revit, we can see that again, it's become a much more efficient system whereby we can design things in 2D and at the same time the building done in 3D at a faster state, you know we can have elevations and sections within minutes nowadays, as opposed to how it used to happen with ACAD. I still believe in, not the old technologies, but the basics you know, like I can never say sketching needs to be phased out for new technologies because I still believe that sketching is fundamental for you to be good in a program, for example. But yeah, before we used to just give a sketch to a client on how something would look, and now there's a walkthrough on how you feel in a building and what you see, you can see every single detail in 3D without actually building it nowadays. But then obviously the cost implications of that are another issue. Calculations before they were all by hand, I mean that's how we were taught at university. We had handmade calculations. I had thick pages of I don't know like a 13-page calculation just to conclude that a slab passes and now the click of a button you can solve that out so. I think those are the main comparisons that I look into. Most of them are the time aspect has changed completely.

Interviewer: And I think the technologies which you mentioned are also very digital. So, whereas before we used to do everything with pen and paper, now we're doing everything on a computer through software, right? Have you met any instances where, you know that there's a new technology that could be used, but it is not being used? And would you be able to describe why this happens, why certain technologies are not being used.

Interviewee: I think the main issue and it's in many programs I've just mentioned. The main issue is the time to learn and the older you get and the more into work and the more busy you get, I think it's harder to actually learn new things, and once you're comfortable with a system in an office I think it's really hard to change the idea and implement it throughout within an office because people get comfortable and when you're comfortable, it's very hard to change to a new idea because at the same time, you need to trust the program enough to know that it's giving you the right answers, the right result, you know, and the time factor is also an issue. I mean, you need to have time to learn, time to waste time learning, you know, and I think our generation isn't as fluent or let's say the younger generations with digital technology are much more, you know, efficient and fast than the older generations. I wouldn't say I'm in the older part, you know, we've experienced life without the digital side you know, like without mobile phones, at least, I think I'm one of the last parts of that generation, but I think the younger ones will find it much easier for them to grab onto new programs because at the end of the day, I think, for example, many of the design programs are fundamentally similar. It's just a question of interface at the end of the day, but once you learn one of them, I think it's much easier to learn the rest.

Interviewer: OK, OK so that that kind of leads us into the next question which is can you think of any common features of the new technologies that you mentioned earlier?

Interviewee: Yes, I'm gonna go back to the basics are the basics you need to know what you're doing. Our lecturer used to tell us garbage in, garbage out, and it's exactly that.

Because if you input the wrong info, you're going to get the wrong answers out and the nice thing about having experience then in the field is noticing that the answers you are getting out are not making sense, so being able to question what you're getting back from a system, from a program. Having said that, the question was mainly on the common features, yes. I think the common features are there. In my opinion it's the interface. I mean, the common features would be building a frame structure. It's always the same frame structure you're always gonna look for the nodes between the frame in any program. It's the same thing, you know, and we're always gonna implement the same building codes and the same standards within the program, so there's all that commonality. It's the same analysis if it's being done with the same code of practices, so I think again it's the interface that makes the difference mainly.

Interviewer: OK, so can you think of underlying skills and values of new technologies which are either common or which may help one learn a new technology more quickly? So here what I mean by skills and values is more generic skills and values like for example, problem-solving, so that kind of skill. Can you think of any other?

Interviewee: In my case, basic physics would be the fundamental part because understanding that, I don't know, if I remove this, that's gonna fall… You know, the physics part of it is fundamental in that case. Obviously, there's the side where you need to know your computer skills, which definitely you need. Problem-solving is also a very valid point. Something else?

Interviewer: Earlier you mentioned that some people get comfortable with using the same software over and over again you get comfortable, so one of the skills… because I obviously have a list of potential skills here… I have, for example, capacity for change, which I think from what you said, you agree with.

Interviewee: Yes, being willing to learn constantly, being open to new technologies and new ideas and having interest to say, maybe fine this program works for me, but maybe there's a better idea nowadays, which can help me be more efficient. Being open to that.

Interviewer: OK, anything else maybe?

Interviewee: Being able to question, we mentioned this so, not being the dummy, like, you know, accepting whatever you're getting back, so being able to challenge what you're getting back from a program and question, does this make sense? I think having enough self-confidence, or enough, let's say common sense to realize that if the answer is wrong. There's something wrong I need to...

Interviewer: Just because the software gave it to me doesn't mean it's right.

Interviewee: Exactly

Interviewer: OK, very good. Anything else you'd like to add?

Interviewee: I don't think there's anything else.

Interviewer: OK, so onto the next question. What would the best way of teaching these skills and values be then? In your opinion obviously.

Interviewee: I think practice always like… Practice is practice. The more you practice, the better you get. But from the mathematical and the physics side of it, that's where I would go, I would learn the science aspect and I would want to learn how to question certain things to be able to reason them out alone in future. But the question how is in a class? The question you're asking me.

Interviewer: For example, think about how you learned certain skills and some of the things you mentioned, how would you describe the way you learned it? Did you learn them sitting down in a classroom or did you learn them more on the job for example?

Interviewee: Unfortunately, in our case, we were never taught any programs we were always expected to learn programs alone. We would be told, listen there's ACAD, learn ACAD. And I would spend most of my hours at home clicking, trying to find out what the next answer is and asking questions, asking individuals who knew the program, what do I do next? So, I don't think it's the best example. But our case, it wasn't the best…

Interviewer: And how would you have improved that then?

Interviewee: I think having classes with people around you learning the same thing, even just practicing and giving simple exercises… I think one fundamental thing that we were missing in university is the practice side of everything. The practical side of everything. I think even in this case having a case study and just going through it together will teach students so much as opposed to learning the theory side of it. In my case, I would have preferred having a project and a lecturer telling. me listen, we're going to solve this today together and that would have taught me 10 times more than just read the book and learn ACAD, you know. I think the practical side of it is fundamental, especially in our field of work.

Interviewer: And what role does the teacher take in this method? So, you know the teacher can take on several roles. They can be just there talking down to you, giving you instructions or they can be a supervisor, they can act like a motivator. What do you think works best?

Interviewee: I think working together maybe would be my answer, in the sense being the motivator and the supervisor, but letting the student experience and go through the difficulties to learn the program itself. So not spoon feeding too much. So, I understand the aspect of having our lecturers letting go and letting us learn on our own. However, I think there was a fundamental part which was missing, which was actually being there and experiencing at least an example together. I would let students learn alone…

Interviewer: OK, so it’s good that they let you go, but not too much.

Interviewee: Yes, but I think they let us go too much in the sense, calculations, we were left to do it alone therefore I used to finish a calculation, I would say, therefore, OK. But I would never have been 100% sure because no one ever really checked my work, you know. Unless it's an exam. So, I think guidance is also key when teaching this kind of material. But the practice, the practicing together, even going, maybe experiencing sites at a young age or experiencing, seeing someone doing the thing you're learning would help much more. I'm the kind of learner where I need to see the global picture before I actually learn the nitty gritty and the details of things. So maybe that's why I'd rather see the practical side of it.

Interviewer: OK, last question, this is a bit of a philosophical question. So basically, if you read up a bit about technological knowledge, a lot of experts claim that it is made up of two components, there's the conceptual knowledge, which is the ‘knowing that’. So, for example, science facts would be conceptual knowledge. And then there's the procedural knowledge which is ‘knowing how’ to do things. It’s skills more than anything, it's knowing how to build a house. OK? Do you think that one type of knowledge is more important than the other?

Interviewee: No, I think they're both fundamental. From my experience we lacked the practical side of it. So, when I graduated, I had zero experience on site, zero experience in offices, I had worked in offices, but when you're a student you’re just given… You know, not given the reality of it. So, I feel they should work together. The conceptual side and the practical side are both fundamental in my opinion, and I think we take the practical side for granted. Or rather, throughout the years, secondary, primary, even tertiary education, always lacked the practical side of it, unfortunately. But they're both equally important in my opinion.

Interviewer: In fact, you'll find this in a lot of texts, if you continue reading, then you'll find that one feeds the other, so it's as you say they build on onto each. Is there anything you would like to add? Maybe something you'd like to point out. Maybe it wasn't an actual question that I asked, but you had a thought and would like to add it on.

Interviewee: Well, one last comment I would add would be, and it stems from another background I have which you know, it's the coaching side. Make it fun. Make it interesting, because I there are specific teachers and specific people who are still up here just because of a comment they made or just because that particular lesson was fun and was interesting to listen to. So, the impact teachers make on a student's life I think is undervalued because it's a huge impact. Many teachers I know changed my life completely. So, make it fun, just make it, you know.

Interviewer: And so, what was the type of thing that made it fun?

Interviewee: I think there were different sides of it, but make it different, you know. You can teach how gravity works by sitting and teaching a class, listen, this is gravity. You know, it goes by this speed, blah blah blah and you explain it. Or you grab an apple and throw it on the ground, and they saw it and you know there's the visual side of it and we made it fun, or you make them all, I'm just setting an example, get an apple at school and do the same thing. They interacted with the whole process, you know, and that helps a person remember it, without even knowing, you know.

Interviewer: Alright, thank you. I understand that. So that brings us to the conclusion. Thank you for your time and for providing insightful responses and I will be transcribing the interview and I will send you a copy of this transcribed interview. If there is anything that you do not agree with obviously, or something that I transcribed poorly, let me know, obviously.

Interviewee: Thank you.

Industry Professional with Mechanical Engineering Background

Some parts of this interview transcript have been omitted to protect the identity of the interviewee. These parts were replaced with the words 'omitted text' enclosed in square brackets.

Interviewer: First question, can you describe your academic or formal training background and what qualifications you have and research that you might have carried out and whether this has influenced the choice for subsequent training.

Interviewee: I have a degree in mechanical engineering from the University of Malta. My dissertation had a focus on manufacturing; *[omitted text].* Then following that, *[omitted text]* I decided to do a masters which was a masters in science in integrated product development, which bridges the gap between manufacturing, business and, you know, design concerns – all into one, trying to find compromises of how to work together to achieve a more holistic, you know, goal related to product development, more efficiently, in a lean and agile way and there were a number of technologies involved in that. My dissertation over there was to try and develop a framework for information management within an organization, *[omitted text]*, how to filter entities across the, you know, integrative product development spectrum interact together with minimal information and data loss to avoid problems over the wall and other stages. Creating a tool which maybe links between different bits of information. It's very much related to what I do *[omitted text].* I started working as an innovation engineer, the first one, and now, over time I've become innovation manager with a team of four other engineers with me, but we work very closely and very openly with the rest of the group because what we do is, we're a support function that tries to have different parts of the group – our clients, sales, administration, production, design, whoever it may be – to achieve, you know, and turn ideas into innovations through the marketing research, design, prototyping, testing, IP, development, tooling. Anything that needs to do to make an idea kind of more commercially viable, we will get involved and it changes for each project. The point is, you have an idea, and you want to make it real – it's much harder if you've never done it before or never done anything similar before. So that's where we try to bridge the gap, in what innovation does, and we support the rest of the group worldwide whether it's Asia, China, Malta, the different sales offices, US, wherever. So, the big focus right now on dispensing systems, application systems, sustainable innovation is one of the biggest drivers, so there's a lot of things that we do do. One of the other areas of responsibility is additive manufacturing and new technologies in general. So, we are champions of additive manufacturing across the group. In terms of prototyping, we've already set up quite a lot, but now we're looking to set up, you know, additive manufacturing as an alternative manufacturing solution for lean and agile manufacturing as well. So that's really what I do and of course, I think it's very relevant to what you're trying to do because I have engineers in my team, I've worked with a lot of interns as well, and summer students as well. We have one person right now, who is a trainee, she is in third year moving on to fourth year, but she is also working in parallel *[omitted text]* to prepare for a future career within innovation *[omitted text]*. I can understand where the needs of the modern kind of industry are.

Interviewer: Alright, so the next question now relates more to new technologies. Can we think of and mention technologies which you have either implemented, started using, suggested or read about recently?

Interviewee: A few different things. I mean, first of all, obviously additive manufacturing and 3D printing, I don't consider it a new technology because we've been using it religiously for like 10 years. But when you compare it to other organizations in Malta and to other organizations in our industry *[omitted text]* we are definitely ahead. We have a global partnership with a company called Ultimaker which we set up to put 3D printers, not only in our design offices, but on our production floor, in our sales offices as well so we can send over parts very quickly without having to ship them by air. We also have two high end project 3D printers which are very expensive machines with higher resolutions in Korea and in Malta. And we also have, *[omitted text]*, a 3D print farm in our factory in Malta to be able to offer additive manufacturing as a solution instead of injection moulding, so that's what we've implemented as a team over the past 10 years. And now we're introducing a prototyping lab, which is to do what 3D printing can’t always achieve. So, it's got things like desktop injection moulding, surface decoration, laser cutting, so it adds a little bit more capability as well and it allows us to quickly turn if there isn't any time to lose. Some days when we’re quoting projects, clients want things done much quicker. The ability to make things a bit more quickly at a lower cost somewhere between a model and a prototype tool is invaluable. Another area we work on is smart packaging, so new technology such as NFC, augmented reality, VR. We haven't really had much success, but we're always, you know, whenever there is a request for that it comes to us usually, and we usually find a way to propose or bring through, you know, the customers mind a solution that works on it. We've come up with some creative solutions, but of course without knowing the software side of things, that's a big limitation on how far we can go. And even if we did know how to implement it, customers would need us to like soft server side and whatever which is not our business. Software is a subscription kind of thing so it's something we're not really into, but I think it shows a little bit of what's lacking in the engineering, manufacturing and design profession. You know this linking with technology, it's getting better, I mean at the last Chamber of Engineers event, you can tell that there's a clear interest towards that direction. But the ability for engineers to get their hands dirty with software side of things, be able to implement solutions over there. So, one of the things that I use a lot within our team *[omitted text]* which is unique compared to the rest of the organization, we have a Microsoft 365 platform, and we have tools like SharePoint and Power apps and power automate and I've been learning a lot more about that. It's like light coding and so on, because it allows you to automate a lot of different things in your process, your day-to-day process. Something that would normally take you 3 hours of data input can now be done with a few clicks, an app or something. Even for information sharing with different parts of the group. And it's become kind of a model for the way the rest of the group works, but it shows how important software is to efficiencies as well I think and that is probably one of the big things that's lacking, we only do a very basic amount of it, and it's usually related to specific projects like MATLAB and so on.

Interviewer: OK, and how would you say that these technologies contrast with more traditional ones? So, technologies which are either used in the past or which have been used for a long time. So, for example, you mentioned that you've been using 3D printing for the last 10 years, but I imagine that you've been using injection moulding, for example, for much, much longer. How would you contrast the two?

Interviewee: I mean, the biggest barrier is that the established technology is always going to have a foothold and it’s always going to win out in the short term. As I said, 3D printing as a prototyping has been a very big, you know plus because there was nothing to compare it to, there was handmade model making which can't compete. Injection moulding has the benefit of having a massive infrastructure within *[omitted text]* the company and within our industry, so we have a massive, you know lots of injection moulding machines, lot of expertise, lots of moulds, but uhm, then 3D printing has the benefit of being quick to set up and so on, no CAPEX. So, there's definitely situations where 3D printing makes a lot more sense than injection moulding. Even with the technology surface finish and speed and technology there's opportunities, so I think they all have their own pluses or minuses, and we have a whole presentation explaining where, you know, you're not going to make an injection mould for 5000 parts, but you can 3D print 5000 parts. And if you design correctly and use the right material and the right technology, you can get very decent surface finishes that the customer who has no other choice would happily accept and even the costs you know, would happily accept. But you find a lot of resistance internally and this is internally not even from clients about surface finish, the time it takes, but it's about planning and capacity though. So, if injection moulding never existed and there was only 3D printing people would adapt, but since they have existing, they know what's better. Then it's going to be a very long time until we can change over simply because of the incumbent technology kind of thing. So that is the biggest barrier, I think. So new people coming in with a new view to new technologies is definitely going to help because when they tackle a problem, they don't just have one tool at their disposal. They now have two tools at their disposal, and they would pick the one that's most appropriate for the situation. Right now, all they see is, OK, we got a new project, how are we going to injection mould 5000 pieces? Because that's the only thing available to them. The thing you can't compare it to is decoration in our industry so when it comes to making parts, there's one technology – injection moulding, alright there is blow moulding, etc., but they're all variants of the same thing. But decoration, you've got so many different options. You got metalizing, you got silkscreen, you got laser, and you can see there's a lot more creativity in how to manufacture the aesthetics. So, it's just that people don't know enough about the technology which prevents… It's a barrier to entry right now.

Interviewer: Right, you also mentioned that, for example, before you used to make models by hand. That's quite a big contrast to making it with a 3D printer. Can you think of other contrasts that are similar or that exists between new technologies and more traditional ones?

Interviewee: It's software as well. Things we can do in software nowadays can introduce massive efficiencies into, you know, traditional processes whether they're soft processes, or whether they're hard process... I'm trying to think of an example; let's say you had to identify uniquely every part that you produced for the customer’s sake, whether it's for security reasons or anti-counterfeiting reasons or whatever. If you have to try and do that with injection moulding and decoration, it would be a massive undertaking with many different moving components, much more opportunity for failure, very expensive. But if you do it with software – integrated NFC or QR, or anything like that – you're going to save so much money in the long run. You're going to save so much time and effort, and you're going to make it more adaptable to future. It's the same as when I told you where our internal processes, we're building up tools based on power apps and SharePoint, power automate, that instead of spending 3 hours doing something, it's a 5-minute thing. So those three hours a day add up significantly and it's the same thing with new technologies and with handmade models – handmade models used to take weeks to produce, we can have a 3D printed part overnight if we really wanted to. I think it's pretty obvious the benefits when you start to look into these things, you know.

Interviewer: So, the next question is actually, I think you've already answered it. It's about the barriers to the implementation of new technologies, which we've already spoken about an. Can you think of any common features of new technologies that you mentioned earlier? So, you've focused a lot on 3D printing, but you've also mentioned that you're setting up some 3D printing farm I think you said, with CNC laser cutters. Did I understand correctly?

Interviewee: Yeah, a prototyping lab.

Interviewer: Like a prototyping lab. So, I would say those are those are, you know, relatively new technologies. Can you think of common features of those technologies?

Interviewee: It's a bit hard to tell, but I mean one thing that new technologies seem to benefit from that a lot of older technologies don't is that in the effort for people to get these technologies into more and more hands so that people can learn about them, use them more – so whether it's a student or whether it's a user – is the miniaturization and barrier to entry. So, there was never any need for injection moulding to become small enough that someone could use that form and that a child could use it because, you know, you were trained up and went to trade school and you did injection moulding. Whereas with new technologies it's all about, how do we make this simple so that everyone can use? Whether it's 3D printing, you know they used to be big industrial machines, now they're things that can fit on your desk and that a child can use. Software you know, new software solutions, making it very easy to code, so there is broader appeal for people to use it. Laser cutting as well, along with different things you know, which injection moulding and other technologies never had to do because it's something you were taught and there was never any need to make it applicable. So, a lot of new technologies have to go through that process. Because when you put it in many people's hands, that mass appeal, there's a lot more awareness of it and a lot more people who are experienced users of this kind of thing, so that's I think a common feature on a lot of new technologies coming right now. The accessibility of them.

Interviewer: Alright, that's very interesting. And can you think of underlying skills and values of new technologies which are either common or which may help one learn a new technology more quickly. So now I'm looking for more generic skills which you might be able to apply across the board, kind of. So, for example, an obvious one usually is problem-solving. People will tell you that if you have problem-solving skills, that will help you to be able to sort of… Looking for that kind of skill.

Interviewee: We were always taught a number of problem-solving approaches when I did my course and my masters. They're all very formal and I don't think that they're bad because they teach you how to address a problem, how to break it down, how to look at alternative solutions, how to do research and so on. So, I think more of that. But we need to get faster at that kind of thing, there is no time in certain projects to sit down to do a proper function means tree, that needs to be done automatically. There's no time to do a DFX analysis with all the different variables. A lot of these things have to be taught, in a sense, this methodology, but enforcing the notion that you need to sit down, write down through the effects on a piece of paper, write down every single aspect of it, that's a bit of a slow-going process, and I think it turns people away as well when they're trying to learn a new problem-solving technique. I think solving problems is definitely a big one and the problems need to be more generic. So, in industry you're going to face problems not only with your specific need, whether it's design or manufacturing or whatever, but you're going to face a lot of other problems that are more holistic. As things get faster, things get more integrated you are not just going to be dealing with the production problem, you are going to be having your upstream or your downstream people telling you what you're implementing here will have an effect on what we do later on and that will be a problem. So, you might design something that solves the problem in your short term, but in long term… So, I think it's that forward thinking, problem-solving as well, trying to be a bit more holistic. And so, it's also trying to learn as much as possible about the entire lifecycle whether it's related to manufacturing or sustainability, it's trying to move away from the bubble. Don't just look at the specific problem that you have, try and understand what your decisions are going to do to the entire project or product lifecycle.

Interviewer: OK, so like a system approach kind of idea. Any other skills or values which you might think of?

Interviewee: I think it's a prioritization, focusing… As I said, the DFX is something I do now automatically in my head. Things move quickly. What is the most important thing that's going to affect what you're doing? And when it comes to a new technology, what are the most important parts of it? You can go through endless hours of documentation, learning about all the different things but there's probably a few things which are going to make the biggest difference to your life and you focus on having a broad knowledge of the entire new technology, or you focus on the specific elements that can add the most value to you, and you know by doing that, you're going to learn a lot more and then the smaller things can come in. So that is really about prioritizing what you're going to learn and how you are going to learn it applicable to what you're trying to do. When you're doing a project, you also won't have enough time to learn a new technology from scratch. You are going to have to learn the parts that are relevant to you and the rest will have to go along kind of. So, it's that prioritization, in the interest of time.

Interviewer: Alright, very good, thank you. And you mentioned problem-solving, you mentioned this 'looking at the whole the whole picture' kind of approach, and this idea of prioritization. What would the best way of teaching these skills be in your opinion?

Interviewee: Uh, I think it's a hands-on with specific examples and so on, so giving… Depends on the age of the students. One of the things that I really like is when there was the robot festival. You see the students who do these hands-on projects, with building and so on within their skill set. So obviously you're not expecting them to build the robot, but they try and solve problems creatively. So, at that level that's really good, because that starts to teach them, OK, to do this I have to go and research what options are available to me. So that's a very critical thing. Then when you get older, giving them specific problems that are beyond their comfort zone and saying, OK go solve this. So, you have an engineering mechanical student, who you know, just uses computers for the sake of their work… Giving them a problem like, we do it in MATLAB, but you know it could be something else now. You tell them, OK, you have to develop a Python script which does this. So, it's not only teaching them Python, which is kind of secondary, it's also teaching them how to learn this new technology, for the sake of, you know, their problem-solving, so a person now complains "I've never used it before", but more than likely an engineering student is going to try and say, OK, I have three months and I have to learn this tool. They're going to find a solution for it one way or another. And whatever they learn, their learning this new technology is going to be applicable. 3D printing as well, you know, someone who’s been 3D printing already would know, but someone who's never used the technology, tell them your problem isn't just to learn what 3D printing is and print something and whatever, your problem is, I have this design and I want to optimize it for 3D printing. How am I going to do it? So having that objective helps you learn a lot more about the technology than if you just show them on a 3D printer, told them, here's how you slice it, whatever. So, it's a hands-on and giving a problem to solve related to the new technology, I think.

Interviewer: What role does the teacher take in this method? The teacher, would they be acting as a manager, as a supervisor, as a facilitator, as a model, as a motivator, what do you think the role of the. Teacher should be?

Interviewee: I think they should always remain as a motivator, that's the point, right? So, it's pointing them in the direction of the right resources, making sure that… It's more when you go off topic and off-track kind of thing. And setting deliverables and their deadlines and so on. And obviously you've shown them so first you give the problem and then you say OK, now if you want, I'm going to do a lecture where I explain what 3D printing is or a lecture on the basics of Python. Then they can decide. OK I need that because I’ve never done it before. Whereas if you just told them, I’m going to do a lesson on it, they say, why would I need this? So, giving them, you know, learning tools, giving them clear expectations, and when they're going off topic or off track, definitely off track, or when they're making a big mistake, you know or something, then they can come in and step in with real experience. So, once you've seen the problem it's easier to accept the solution rather than if I came in and before you even started, telling you, yeah, your 3D printed part, you should probably slice it at 0.2 layer height and give what settings to put in the machine, because that means they won't experiment and say why am I using this setting? So, it's when something is going wrong to step in. It's much like a manager in a company, you don't do everything yourself you take away the obstacles that are people's way so that they can achieve the job.

Interviewer: Very good. Now this question is a bit more about technological knowledge in general. There's several authors who have posited that technological knowledge is made up of two components, and they usually split them up into conceptual knowledge and procedural knowledge or 'knowing that' and 'knowing how' so some examples of conceptual knowledge are for example, the laws of thermodynamics the laws of motion, material properties and so on and some examples of procedural knowledge then would be design, modelling, problem-solving, project planning, quality assurance and so on. Do you think that one type of knowledge is more important than the other?

Interviewee: Me personally, I'm a much stronger believer in procedural, but that's me. I don't think it's a bad… If I went to everyone from my year of students and asked them, OK, what are the heat transfer equations? Myself, number one, I would not be able to tell you. But I know they exist. I know that if there is a problem related, I'm sure there's like one or two who are working in the industry who use them, but they probably made computer models and don't remember them. So, it's one of those things where knowing that they exist is good, so knowing that if I have a problem in my specific subsets that requires modelling of heat transfer, I know where to look. I know what I'm looking for. That is, again, part of the problem-solving approach. So, if you had to tell me, you need to know how to use these… What we're going to do for the next nine months is learn how to use these models 100% effectively, I think it would be more optimal that you show, to give a problem on how to use them, learn how to use them once or twice, but then you kind of put it at that. It's not like you have more complicated and complicated problems. I mean, in engineering we're always told that if there's something you don't know, you ask more competent engineers, part of the way we work. So, I definitely think if you're going into research, conceptual knowledge makes more sense, if you're going into industry, procedural knowledge makes a lot more sense. It doesn't have to be hands-on, because all we're doing basically is creating technicians but on theoretical... So, you're creating a technician who instead of using the hands-on, the technician on the theoretical. So definitely procedural is more important in my view.

Interviewer: Is there any further information that you would like to share? Maybe something that you'd like to add?

Interviewee: *[omitted text]* I'm a bit out of date what they teach. What I learned now is from what the students tell me, and they still do, tell me that there's quite a lot of things which I would have changed which are still there, but there's also new things. But they're still missing... And if they're missing at university, I assume they're missing at upper secondary, and I assume they're missing even lower down. That, you know, things like, 3D printing, programming, technologies, still aren't as big. We keep talking about them and how they're important, but they're still not a big thing. So, if you have these people creating a curriculum for these new technologies, they are going to mention them as a new technology always and say this is a new technology, it's a developing technology. But when you say 'developing' it kind of indicates that it's not ready to go yet. But in reality, it's a technology that is very viable for a lot of different things. So, it is a technology available to you.

Interviewer: And by using it more, you're actually developing it more, right?

Interviewee: But it's also the point that, you know, the people who are setting these curriculums and the ways and methods of teaching, it's going to affect the way people are learning these things as well, so that's something that probably needs to be addressed in general so. It's very easy to address. It's basically saying, OK, we're going to talk about 3D printing, we're going to give the problem. You don't have to teach it. I'm not asking you, to teach about 3D printing, but here is, you know, a set of… Give them a problem to solve, here's the equipment, now let the students do it and you just act as the barrier remover. So that's the one thing, I think. And when it comes to new technologies, we have to be very careful in the language we're using. You know, things like 'developing'… OK, every technology is developing. Even injection moulding is a developing technology, if you call one developing and one established, that's a problem. If you say 'infrastructure', things like that. These are problematic words, so we need to treat new technologies as technology and not like, you know, nice, new whatever. And, again, 3D printing but it applies to software, it applies to modelling, it applies to VR, it applies to AR. We need to stop sensationalizing them basically and just make them more normal and real.

Interviewer: Alright, so thank you for your time and for providing insightful responses to my questions, they will surely help. I will be sending you a copy of the transcript once I get around to transcribing it. If there's anything you'd like to change, or if maybe I've interpreted something incorrectly, obviously, please do let me know then. That's it from my end. Thank you so much.

Interviewee: No problem. Thanks.

Design & Technology Education Officer

Interviewer: The interview is split up into a few sections basically, so I will begin by asking you questions related to your academic and professional background, we will then progress on to questions relating to new technologies and the associated skills and values and their teaching and finally, your views about technological knowledge in general.

Interviewee: Very good.

Interviewer: So, question one, can you describe your academic or formal training background to me? What qualifications you possess any research you might have carried out, and whether this has influenced the choice for subsequent training.

Interviewee: Yes, I'm graduated as a Bachelor of Education in B. Ed. Technical Design and Technology. I started my course in 1998 till 2002. In that period the subject was still starting in Malta, so we were the runners up to start the syllabus actually, I was in the second group. My interest in this area combines not only the specific pedagogical aspect, but I'm much interested in the line of product design. Basically, I am very motivated in the area of product design and also innovation. Following that course, I had started work, as I said, the subject per se design and technology started a bit later on in 2006, so also within this training includes the content and the teaching and the pedagogy for teaching technical drawing, or graphical communication. So, I spent the first four years of my teaching career teaching mainly graphical communication in a junior Lyceum girls school, actually, it was called Maria Regina in Blata l-Bajda and basically, following that I was able to introduce the subject in that school in 2006 where we set up the laboratories, I also had followed two or three years of training with DTLC at that time, it was just set up already, where we could also benefit from hands-on skills training, something which complements a bit the theoretical approach done in university where we did have some facilities but training would have needed a bit more skills in that aspect. Following that, after 2011, I started my master's degree and as I mentioned before, my dual interests in the industry of design, and also in design and technology, paired also with my lecturing at university and my private practice in product design, interior design and custom design, I embarked into a master's degree with Northumbria University about multidisciplinary, innovative design. So, it could take my educational part of my career and also my commercial aspect in the design area and combine them into a reflective practice master's degree which actually involved a professional practice approach where I was able to look at all the strands which I'm taking care of; both the educational part, the lecturing part, the commercial side, my projects and where I'm going, into one single master's degree, which actually led me to discover more about design thinking, more about multicultural approaches to designing, more about the cutting edge industrial aspect of design, like intellectual property and so basically it gave me a good edge on both areas both the technological part and the educational part basically. The creative and the educational which work together always in design and technology as well. So, following that I started in this role, which I am today, as an education officer for design and technology. My role is on a national level to represent the ministry for every decision about the subject, about recruitment in the subject, about new staff, about new equipment and I take care to develop curricula and support teachers and educators, and obviously, students in this subject. Sometimes I have to do the PR aspect of the subject as well, to promote it and to bring it to the attention of parents and schools and other educators and obviously, I'm the support person for the teachers in design and technology. Throughout my carrier I was actively involved in the commercial side of designing, taking a multidisciplinary approach in product design, architectural interior design, graphics, branding and exhibition design. This aspect always gave my deeper insights about this industry and fed my creative needs, somehow complimenting my current role, which takes most of my time.

Interviewer: OK, so now we're going into the part of the interview which relates to new technologies. So, can you think of, and mention, technologies which you have either implemented, or started using, or suggested, or read about recently?

Interviewee: OK, the concept of 'new' is very subjective. Let's say, what is perceived as new, I would say that every time that we use, CNC equipment or 3D printers or laser cutters – all that is in the digital manufacturing sphere, is generally taken as new, but again, some people would refer to an LED as something new despite being there from 60s and 70s. But, in concrete terms, we have implemented CNC equipment in our schools since 2010. Following that, in 2015, I had managed the 3D printing introduction project where we introduced eighty-six 3D printers to cover two in each of our labs actually. So, in that aspect of CNC, if you consider them as new technology, we're already implementing them. Other than that, we are working a lot with microcontrollers nowadays. So, in terms of systems and control, we have moved a bit further away from discrete electronics, but still keeping them because you need the foundations, and moved into, let's say microcontrollers which can be programmed visually, because in design and technology, we don't focus a lot on coding. So, flowcharts programming approach to microcontrollers is our main focus, but they are allowed to use any other approach as well. Other than what we have now, what we are looking at, is the introduction of the concept of emerging technology. In that sense, it's not only the cutting edge, but we are surrounded with many smart devices around us in terms of able devices and we've been feeling the need to step into this area in the syllabus for quite a long time now, and it's the right moment now where we are writing the new syllabus 2025. Despite looking deeply into emerging technology, it is a very dynamic area. So, what I am mentioning in this new syllabus, is that there is a very vast range of new technologies which students encounter every day. They are rather new and emergent, and they are the future – like embedded Internet in devices, like digital manufacturing is also one of these areas, alternative technology, alternative battery technology, alternative energy. We are considering them as one aspect that a student should be, firstly aware of, at least on a selective way or on an elective way, a student should be able to follow some interest, not all of them, there should not be a part of this discrete syllabus, but at least if you're interested in one of them, you should be able to hold an interesting discussion about it, and maybe propose it as a further development to your project. So that's an approach we're taking that is a works in progress, basically.

Interviewer: OK, very good. How do these technologies contrast with more traditional ones? So, technologies which were either used in the past or have been used for a long time.

Interviewee: It does contrast. For example, one of the items we are mentioning is Industry 4.0, right? It's not a manufacturing technology in itself, but it's an industry approach basically, and there's this big shift from the production techniques and methods found today to a more customizable way of working. Even if I give an example to students how they order take away today. I mean, you can also mix and match between different restaurants from certain apps, so it is an industry 4.0 exemplified in everyday things as well and this should change a bit the way you think about production scales, the way you think about batches, about just in time production… So, we are trying to instil these primary concepts of the new way the industry works. They don't contrast. I think they all build on what we have. If I have to give a more clear example, let's say how a digital manufacturing device like at 3D printing workflow contrast with a handsaw and a chisel. They're both tools, so I would present them as they are both tools and the thinker and the mind is still the same person. But you cannot just say, OK, instead of cutting with this, I'm cutting with a 3D printer or similar. You have to take a different approach towards new technology. Sometimes people think that it's either sketching or working on a digital model on a computer. I experienced that myself as a designer where before I did only sketching, when I learned different software, I did not just do only digital designing, I started to merge my sketching back and forth with the digital modelling up to a point where sometimes you don't even catch a pencil while you're doing that, but it's still there, so one builds on another they take different starting points, but it's an added skill and an added tool in the way I see it.

Interviewer: And can you mention barriers to the implementation of new technologies?

Interviewee: Yes, especially in terms of assessment there are some barriers, because if you want to assess a student how well they are versed, or how well they are aware of, let's say, a new 3D printer which has an embedded technology within it. Let's put an example of a new device, OK? These are very dynamic, things change a lot, so you cannot say I want to learn, or I want to assess how well they know this machine. It takes it a bit on a higher level. You want to assess their ability to grasp new concepts, so it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow. So, some people, even some teachers, would resist that a bit because they say listen, I'm not trained fully with the software, so their barrier is I'm not trained like I was with the particular hand tool for this, so they expect that training to be fully spelled and shown. Whereas the barrier is more a psychological one that people think that I have to have all the documentation in my hand to do this, whereas even if you see a 5-year-old today, if you give them a new device, they would need no paperwork, no explanation, just leave me alone, I will intuitively do this. And that is a barrier for me.

Interviewer: OK. And can you think of any common features of the new technologies that you mentioned earlier or in general?

Interviewee: There are some common features. The fact that most of the time they involve digital technology, it is a common feature. And there is this perception that, it's either you're that kind of person that can indulge into digital work, or you're not. So that's a common feature, a common barrier sometimes, which it's mostly with the elder people, not the students. The students don't have that very much. It's just how you present it in the first place, I think. Other than that, I don't think there is a financial issue, I don't think that is a barrier at this point. Affordability is very high for schools, for individuals, for the backyard inventor, they are accessible these items. Even for logistics and supply, I think there is no barrier for that as well. You can get access to anything nowadays, even locally. Most of the time it's human resource issues, that's most of the of the barriers I believe.

Interviewer: And that's probably related as well to the age of teachers and people teaching.

Interviewee: Or the mindset. Sometimes it's the age, sometimes it's the mindset.

Interviewer: It's more the mindset I think because as you said, the students are willing and happy to try things. OK, next question. So, can you think of underlying skills and values of new technologies which are either common, or which may help one learn a new technology more quickly? So here I'm thinking more about general skills and values which, if you have them, you can sort of, they will help you learn new technologies more easily because as we said, new technologies are coming out and they change quickly.

Interviewee: Yes, I think there is a basic skill set that that one needs to have. It has to build up from your technological literacy basically, that's the first skill set. I'm not referring to typical ECDL skills obviously, because they should be core. Those aspects I agree with the new development there was in ICT teaching in our secondary schools where we don't have ECDL as being the ICT lesson because that's also a problematic mindset: "Computing is doing Word, doing Excel", which it is not. So, we are happy to see that with the new subject ICT in state schools, which is the C3, we're seeing a shift that actually addresses these skill sets. We're seeing students which are able to download a program themselves, do some scratch coding, do some visual presentations, maybe using a new software there and then, maybe do some game development. Because it makes them confident with approaching intuitive situations. Because let's face it, maybe when I was young, a software was not intuitive, you had to do everything yourself, maybe sometimes using DOS, and maybe sometimes being like almost a hacker, to actually use a package. Today, it's actually literally impossible to not make something work. So, it's more like there is this barrier that you don't want to try and get into something and try it. Because at one point, when you open even, uh, let's say, a slicer for a 3D printer, OK? Now you have diverse soft apps that you can download any type of STL and file to get them into your software, so you can get all your files from anywhere from peer sharing. You can get your own file designed from your friends or yourself and now you're going to slice an object on a 3D printer. So, what's the burden? OK, you need to have a grasp of the jargon, sometimes if it's, let's say, you need to know what infill is. Someone has to give you those basics. So, in terms of skills, skills are quite simplified nowadays because it's different from trying to learn exactly how to hold a mechanical tool like a hand saw – you need to have a good position, and good posture, and good distance from your bench. So that one would have typically required a specific guidance or instruction. Nowadays, with digital skills, someone has already thought out that process, that it is a bit easier because it actually involves mainly hand to eye coordination with your mouse and with your screen, and so that aspect is less, you need less of an instruction to do it. The software will be guiding you throughout, either with a wizard or else with some sort of some help or assistance within the software and so to have the skills, I think it's easier right now. You don't even need to be particularly skilled technically, or particularly skilled artistically, which before were more accentuated, before this. In terms of values, I think it's the mindset, as we said before. So, students are a blank canvas I think, they will get those values intrinsically into them because they don't find it challenging to shift to a new paradigm of working because it's a new paradigm anyway for them. So, in the sense of value, you might still have some students, or some people who resist, so that's a negative value which actually, like they are building up a barrier themselves, I think. In terms of knowledge, again, we're living in the information age and there is nothing you cannot find in any case of knowledge. I'm not saying that we don't need knowledge or knowledge is not important, but it is more accessible today. So even if I'm trying to unbox a completely new device there is information everywhere, there's videos about it, there's people doing exactly the same thing and reviewing it, so there is knowledge. It's just also not delivered in the same way as before. And on that point, I would say that even nowadays, if the information is made available like it was before, so you have to find that book, or find that file online, whatever, and you have to read it, there's still resistance to that approach, because I believe that nowadays, people tend to not want to have the full book and then go to do something. I believe information has become like an extension of our body. It is there, you call it, and you need it, and you look at it whenever you need. It's not like you have to fill the battery with knowledge all the time to start working. I think that covers skills, values and knowledge. Let me know if you need more.

Interviewer: Therefore, what would the best way of teaching these skills and values be? In your opinion, obviously. How do we go about teaching them?

Interviewee: So, to teach them, it depends how you want them to learn them. So, in my opinion, to get someone to learn these 3 concepts; skills, values and knowledge for new technology, do you want them to learn them that they can elicit them? Do you want them to learn them so they can use them? Or do you want them to learn them so basically, they can be certified that they did this? So, in the first place I would say that learning these aspects to build your mindset is my main goal. That's what I choose. I want them to have this mindset because if I'm teaching them in 2022, how to start working on a 3D printer, and they go to work in 2028 for example, where the device will be completely obsolete and everything has changed… OK? so teaching them particularly how this printer works or how this technology is operated actually, is… It was good in 2022 because I could assess them, but until 2028 I need to leave something from that knowledge. So maybe the value I would have left, and maybe the foundation of knowledge. This skill will change for sure. This skill will change. OK, there will be some enthusiasts who go into skill and become really, really good at it and they dismantle a machine themselves, build another one, change parts. That's good because those are the enthusiasts, but what I would actually give importance in the teaching aspect, is that the moment you are teaching them is an experience and then experience is the only thing worth to spend your time on actually. It's not worth studying by heart, something which, when you're finished with your assessment, will actually change. So, in my opinion, it's putting these three aspects, these three items; some skill because you would have needed it to make the experience more positive, value is very important, so it's always important to give the why are we teaching you this, it's not just for the assessment, and eventually you have to open the doors for knowledge. That's how I see it. If I can add, in the sense of what is being taught today, that is actually the direction of our new syllabus; less prescriptive, so it's less about this knowledge. We want to have a better experience, but then again, if it's a course which is assessed summatively, so your marks add up, you are bound by other rules. You are bound that by this time you have to finish this, and you have to put this in right now and right now I want to check this learning outcome. It's a good thing that the subject is still a spiral one. So, you're not confined to tackle a chunk of skills or knowledge at one go, you can still live it as an experience. So, you go back and forth from knowledge to practice to application. And I think design and technology has always aspired to go that route and this lasts iteration of the syllabus, accentuates that. It's giving more importance to this formation of values. To simulate the right experience within the structure proposed by MATSEC in coursework basically, and also to give the sufficient skill a step at a time, but it has to be also manageable.

Interviewer: OK, so what role does the teacher take in this approach of teaching, design & technology?

Interviewee: Yes, the design and technology teacher actually has to take many, many roles and wear many different hats. Sometimes you're the facilitator towards this different world. You're trying to show them that it is one of the best human achievements to be able to change something to achieve a particular result. And to do that you will not being showing the students, let's look how good am I, how good I am to do this. You're actually giving them exposure to a real-life success story, why not? Or case studies. But you have to give them small experiences which scaffold one to the other, that show that yes, I made this, I managed. I actually designed this part. I actually implemented this part. So, the teacher has to be the organizer of many little steps of wicked problems. Basically all that is in design and technology is mostly based on this concept of a wicked problem where they have to solve something fictitious, it is for a client which they actually don't see, and it is for a product which actually, in the real world, is sometimes surpassed much, much more in the real world, and the design and technology teacher has to actually give the narrative that you are actually living this, for example, at school, and immerse them into this experience. So, in terms of values, that is the role of the teacher. In terms of skills, there's this dilemma where the technology teacher needs to be really skilled not to misguide or mis-show a technique, but then again, most teachers tend to seek further training, so they don't actually show something wrongly because there is safety involved. For sure. It's very important, OK? But the role of the teacher actually has to be to present technology in the right way, in a safe way and also to show that there is more training to get. Because there is a culture nowadays that even if you saw a YouTube video, I know it. Which is a problem. And let alone if you get an expert in front of you, the teacher, and so you listen, you use this machine, like this, like this, like this. So, I'm not an expert, I'm a super expert because I not only saw the video, I had the teacher telling me this. So, the teacher has the responsibility to make students realize that there are many ways to fail, and that's important. In terms of delivering knowledge, it's important to teach them how to learn. That is the important role of the teacher. Then again, I might sound that I'm saying very ideological concepts because on the other hand, there is this school syllabus, there is the MATSEC syllabus, so these would have a structure which then the teacher has to be the organizer to make it work in a realistic way. So, I think ultimately, it's keeping a balance between the ideological aspect of values and responding to what assessment requires.

Interviewer: OK. Very good. OK, so this last question is a bit more philosophical, so to speak. It's about technological knowledge. Often, we read in texts that technological knowledge is made up of two components. There is the conceptual and the procedural knowledge, or the ‘knowing that’ and the ‘knowing how’. Basically, in the case of procedural knowledge, there is design, modelling, problem-solving, systems approaches, project planning, quality assurance, and so on and conceptual knowledge then you have circuit theory, laws of science like thermodynamics, laws of motion and material properties. Do you think that one type of knowledge is more important than the other?

Interviewee: There are different approaches to it. I had discussions with, let's say, engineering course coordinators, I mean engineering at university level, who would insist that ‘knowing that’, the approach of knowing the foundational knowledge at first hand, like having the full book covered, before going into ‘knowing how’, is very important. Obviously, it is a higher level, but if I stick to our level, so let's say middle and secondary school, it's mostly striking the balance between ‘knowing that’ and ‘knowing how’. But students will ask the question, “why do I need to know that this is this?”, and “why do I need to know how to do this and this?” So, it adds the third column which would be, knowing why maybe, because it's a big question. They feel “why am I learning this? How will I use this in my future?” And it's true, it's a change of values in terms of students. So, if I had to choose between the two options you gave me, I would say I cannot choose, because one leads to another and vice versa. I'm the type of person who would only learn something after quite a good number of mistakes at trying to do it. But then I would know it, because during that process I would have gotten to know better why or how to do it properly and probably I would have searched couple of times what it is that I would have wanted to know. I'm that kind of person. I try to give out that approach to teachers as well. If they are the holders of how and every knowledge, they are set to not succeed, I think. So basically, knowing how to learn how and that is more important for me.

Interviewer: So, is there any further information that you would like to share that we have not covered maybe? Something you'd like to add.

Interviewee: Maybe I can add some, let's call them hints about this syllabus that has been already launched for design and technology. We are looking into a framework where, as from year nine, students are already enrolled in their subjects, so they will have year 9, 10, 11 to achieve their MATSEC qualification. Having said that, from year 9 they start coursework at school, which beyond that which we know right now, because even in the current syllabus we have projects and also a bigger project at the end of the course, but from this new syllabus we will start seeing that even year 9 material is assessed at MATSEC. So, they will have 20% in year 9, 20% in year 10 and 10% in year 11. Building up a 50% assessment on coursework, which is the biggest percentage in all the academic listed subjects. So, with the new syllabus, we're going to see that what we already had achieved in design and technology, which is a 50% aspect of course, is now formalized, and it will be a continuous assessment for our students. What we have also developed is a non-singular approach to the design process. If before we used to have a very structured, typical, design process with 10 stages, we broke that aspect completely and we're looking into the broad design process. So, it's explore, design, make, and evaluate which you can change non sequentially all the time and we could also be able to teach students how to design an object in different approaches. It's not always that you have to have the design brief and then you start research and then you start making and then test and you evaluate. We did reverse engineering approaches in a small task with it, things that are design only. So, you would start from a concept and dream big and try to get a realistic concept, not making it. That's ideal for also emerging technologies, because sometimes you need to talk about "what if?" "What if I add Bluetooth to this device?" But we don't want to go into the nitty gritty of exactly implementing a Bluetooth device. So, it's a blue-sky thinking approach. Then we also had other approaches like pitching design ideas, so it also enforces other skills which I think are more transferable in today's life because it's like a very, very entrepreneurial world, the word of technology nowadays, so it's an important skill which we're seeing. And besides that, I think there is a good development in terms of a small reduction in the prescriptive knowledge. We are reducing a bit aspects of some discrete electronics which we had. So, when we were talking about timing, we don't need to say astable and monostable, we can say, there is a timing approach, don't even go into R and C, resistance and capacitor approaches, because it's actually available in many different routes. Microcontrollers, through coding, through other devices, embedded electronics. So basically, on the whole, we're trying to go into the direction where skills and knowledge are a bit less the centre stage of the syllabus and I think the value has become increasingly important. In my opinion, we're implementing this by striking a balance between how value is presented as an abstract thing, and how you present it in a practical way. Because if it's abstract, on the other hand, it becomes less of an experience, that's it.

Interviewer: OK, very good. So that was the end of the of the interview. Thanks a lot for your time obviously, and for providing responses to my questions.

Interviewee: You’re welcome.

Interviewer: I will be transcribing the interview and I will be sending you a copy. Just in case there's anything you would wish me to change or whatever, obviously let me let me know.

Interviewee: That's no problem, OK.

Design & Technology Head of Department in a Church School

Some parts of this interview transcript have been omitted to protect the identity of the interviewee. These parts were replaced with the words 'omitted text' enclosed in square brackets.

Interviewer: The first question is: can you describe your academic or formal training background to me? What qualifications you possess, any research you might have carried out, and whether this influenced the choice for subsequent training.

Interviewee: *[omitted text]* My background, basically I entered university without knowing exactly which course I want to read. There was this opportunity that a new subject was being launched, which was design and technology. My only knowledge of design and technology was the fact that it involved building stuff with students. As a young child I used to love spending a lot of time in my father's garage with experiencing materials, he's a carpenter. So, I thought listen, I feel very confident with using tools and materials and I chose to let's see what happens during the subject basically. My background at school as a secondary student wasn't too happy because obviously my love to materials and tools wasn't really appreciated in my time because obviously academics took over any other form of education basically. So at least I said, listen, maybe at university, I'll find my niche. I was lucky enough that this subject ticks all the right boxes. I enjoyed my time at university. I enjoyed my time teaching this subject. *[omitted text]*

Interviewer: The next question was actually about work experience and professional background, so I think we've already covered that, because one leads to the other, obviously.

Interviewee: Just as a side note, my love for tools and materials obviously doesn't stop at school. I run a small shop where I occasionally do some jobs for clients, or the occasional clients or friends. So, I've got quite a well-equipped workshop with metal tools woodworking tools, fiberglass… So obviously I try to keep myself up to date.

Interviewer: Yes, that's very good obviously because you need to stay current. So, the next question now is about new technologies. Can you think of and mention technologies which you have either implemented, started using or suggested or read about recently?

Interviewee: So, when we talk about new technologies, obviously it's always relative, because obviously some new technologies that were available in the beginning of my teaching career are today maybe also obsolete. Talking about having projectors, having these tools that we used to teach, resources used to use, or other machinery like lathe for example, which were new at the time. Today, obviously, we have to move forward with integration of computers now moving also to the integration of Internet of Things. So, yes, I have made large efforts to introduce the use of CNC in schools, lucky enough in my school, we've got both a laser cutter and the 3D printer, but I always focus on the fact that the tool itself, is not an end to itself, so new technologies are just a means. So, when I deliver lessons to students, I don't focus on, listen, you have to use one of the latest emerging technologies, but obviously students, while discussing how we can move forward, how can we make this product even better, the use of current technologies will then be applied to a particular scenario given to the student.

Interviewer: How do these technologies then contrast with more traditional ones, so technologies which were either used in the past or which have been used for a long time?

So, you mentioned, for example, CNC and 3D printer... For example, the CNC, how does it contrast with cutting with a hand saw for example.

Interviewee: At our school, thanks to the fact that we have a laser cutter, we have implemented, also as part of the project that students carry out in the year 7 projects, so the first time they start to experience design and technology, we make it a point to introduce technologies that are available at the moment. So basically, what we teach students is the fact that thanks to these new technologies we're saving time, we're being safer… How? Because they can see that after making their cardboard models, after testing it out, they don't need to manufacture it. Then they just feed the information to our CNC and the CNC will build, will cut the material for them, quickly accurately without too much danger for the students themselves, so they can actually see how quick it was. We just made a cardboard model; we fed this information to the PC and the PC talks to the machine and the machine then made our product. So, they can see that, listen, technology is helping but in many different ways. Being time, being safety, being accuracy, and cost, obviously, because we're saving material because well before, for example, explaining to them, just to make it easier, for the teacher to deliver lessons we used to give a set material to each, so four sheets of plywood each student. Today, we don't do that anymore. When you do that, you have a lot of waste. Now we don't do that anymore because we are generating parts on the PC, we place all the parts next to each other, we nest all the pieces on one large A3 sheet without having any waste. So also, students can appreciate the cost benefits of using new technologies.

Interviewer: Very good. Can you mention barriers to the implementation of new technologies?

Interviewee: Well, the biggest barrier is the financing of it. I mean, I was lucky enough that the school was ready to invest, I understand that not all schools have the same budget or the same priorities that my school has, so the biggest issue with technologies is basically money. It's the funding of these technologies. A second problem with these new technologies would be time for the teacher to train and be confident enough to use these tools there and then in class with the students. But knowing our teachers, I'm very pleased to say that most of our teachers are very hardworking people and they love the subject, and they would be more than willing to learn how to use new tools. So that is not the biggest issue, even though it can be an issue, because obviously teaching loads are quite high, the demands that are put on us are quite high, so yes, I understand that some people might find that difficult, but it's the least of the issues. The biggest issue, in my opinion, is always the funding of these new technologies.

Interviewer: OK, and can you think of any common features of the new technologies? Perhaps that you mentioned earlier?

Interviewee: In my opinion, new technologies are there to make our life easier. They make it less expensive, could be making it safer, could be making it quicker, making the process much quicker so we can have the product in hand much quicker, you know. So basically, it's making our life easier.

Interviewer: Can you think of underlying skills and values of new technologies which are either common or which may help one learn a new technology more quickly? So, I'm thinking about more generic skills and values that can be applied more widely then. So, you learn a particular skill that isn't just useful for when you are, 3D printing, it's also useful if you want to learn another technology.

Interviewee: OK, in my opinion, the key skill that one should learn is actually being able to change, being ready to accept change, rather than, I don’t know, knowing how to use CAD, which is a particular software right? I don't see that as the key feature because technology is progressing very quickly. CAD might be a high-end tool which after all most makers don't use to the full. Today we've got access to much cheaper software, maybe also that’s easier to use. I mean, let's talk about some stuff like SketchUp. Let's talk about Tinker CAD. They're easier to use and maybe you don't need to know how to use CAD at the level that CAD allows you, but I think that would be enough, for example, for you. So, it's not the software per se that I think is the most important thing to learn. I think it's more an attitude that we need to accept, to embrace, that listen, technologies will change, be ready to adapt. That is the key aspect that I wish for my students to learn, basically.

Interviewer: OK, and what would be the best way of teaching such a skill or such a value?

Interviewee: It's important to find a need. If we are able to make our pupils understand, open their eyes, understand, that there is the need for you to learn how to use this tool, then things will be much easier because if you see a reason for a particular lesson, for a particular skill that I need to learn, then obviously you'll embrace that and you'll learn it much easier. If I make you learn about something, you won't learn it really well. I mean, it’s much harder for the teacher to deliver the lesson, much harder for the students who accept what's happening, so giving a purpose and making students understand the purpose of a particular technology will help students to learn, to make them independent learners. Even though it's a catch phrase, because it’s being used and abused basically, but I think, I truly believe, that our students need to understand the need. Once they understand the need, I'm sure that they can find their own ways and means to get to the goal that they are aiming for.

Interviewer: OK, and when you say, “finding a need”, do you mean through a project, for example?

Interviewee: It depends. Let's talk about a specific particular setting in the classroom, I never teach students how to use a 3D printer. That's not my aim. I set up a project where they understand that 3D printing would be an ideal way to solve this problem. So should they need to use a 3D printer, there is when I start teaching how to use a 3D printer or what a 3D printer is. So, they have a general knowledge of what it is, but then I do not make students use a 3D printer. They need to feel the need to use the 3D printer, so then they'll obviously need to know how to use the software, so you know, having students identify the need and then accepting their questions and answering their question basically.

Interviewer: So, what role does the teacher take in this method?

Interviewee: I believe that all teachers shouldn't actually be giving much. What I believe a teacher should do is entice students. We cannot take all the students to one particular spot because that's not the aim. I mean, in my opinion that's not the aim for schooling. So, we're not taking all students to reach a particular point, and if you don't reach that particular point, you’re a failure. So, what I think is, what I believe is that teachers should be just guides, they should help each student find their own goal, find their own targets, and help them reach that goal. Obviously within limits, obviously I mean, we have to always push our students to do their very best and help them and guide them to reach their very best.

Interviewer: OK, so, the last question is about technological knowledge in general. Basically, we often read in literature that technological knowledge is made up of two components and you have the conceptual knowledge and the procedural knowledge or the 'knowing that' and the 'knowing how'. As examples, 'knowing that' or a conceptual knowledge would be circuit theory, laws of thermodynamics, laws of motion, and that sort of thing. 'Knowing how' then would be design, modelling, problem-solving, system approaches, project planning and so on. Do you think that one type of knowledge is more important than the other?

Interviewee: No, definitely not. In my opinion, you cannot understand how to make something before understanding why. So obviously they have to go hand in hand, and I believe that it is like when a designer doesn't know how to use a particular material, but then designs a particular product. Imagine having two opposing ends, let's have the designer and the technician basically. So, it's the person or the fabricator. If the designer designs something, when these plans are given to the fabricator, the fabricator has to say how this needs to be made. If the fabricator says, listen, there's no material that can withstand that kind of pressure so it's impossible to be manufactured. I think the technician was right in saying that kind of comment because obviously technician the expertise is in is the 'how'. The designer wasn't an expert in that right? So, there would be some misinformation between them the same the other way around. So, the person manufacturing the product needs to have skills on the "whys", why certain tools, or why certain joints are use, you know? The reason behind… I mean, people might learn to do something just because it's a traditional way to do it, but not understand the why. So, it is very important that both of them… I mean, that's why we... I believe that our students should be able to design and make because obviously they go hand in hand, so they'll be able to know the why and the how, because that's how obviously you get the best out of the material that you are, or your best out of your design, that you are building.

Interviewer: Exactly. So that was the last question. Is there any further information that you would like to share? Or maybe a comment that you would like to make?

Interviewee: Uh, there's not much to say because I think I have said all I had to say. Hopefully I answered all the questions.

Interviewer: Yes, it was a very good interview, very fruitful for me at least. So, thank you for your time, your answers will surely help my research. I will be transcribing the interview and I'll be sending you a copy of the transcript. If there's anything that you would like to change or clarify, maybe I would have transcribed inaccurately, obviously, feel free to get back to me and I will update.

Interviewee: Should you wish any clarification on my answers, don't worry just contact me and I'll help you out.

Interviewer: Thank you.

Appendix C – Opportunities for learning D&T skills and values in the NCF

Table 6 Opportunities for learning the skills and values listed in Table 5 in the NCF document

Skills and values required to harness new technologies combined from literature and interviews	**'X' indicates opportunity to learn skill or value in the NCF**	**Comments**
Design process and thinking	X	
Curiosity	X	
Formulating the problem		*May be too specific a skill for NCF*
Problem-solving	X	
Creativity	X	
Innovation	X	
Multiple solutions	X	
Collaboration	X	
Communication	X	
Self-directed learning	X	
Independent learners	X	
Professional development	X	
Metacognition	X	

Knowing where to find knowledge	X	
Taking intellectual risk	X	*NCF mentions risk-taking several times- assuming this extends to intellectual risks*
Interconnecting knowledge	X	
Pattern recognition/ Pattern sniffing	X	
Knowledge transfer	X	
Transforming scientific concepts into intermediate concepts		*Discussed when dealing with NCF's limited view of the relationship between science and technology (technology as applied science)*
Systems thinking	X	
Synthesizing	X	
Analytical and critical thinking (openness)	X	
Open-mindedness	X	
3 Dimensionality		*May be too specific a skill for NCF*
Sketching		*May be too specific a skill for NCF*
Making value judgments		*Discussed when dealing with NCF's limited view of the relationship between science and technology (the normative aspect of some forms of technological knowledge)*
Ethical consideration	X	*NCF mentions ethical consideration more in relation to developing students as individuals that are capable of functioning in society rather than in relation to technology.*
Decision-making	X	
Modelling		

Adapting Improving Optimization	X	
Prototyping		*See discussion for 'Modelling'*
Testing	X	
Re-thinking		
Ability to change	X	*NCF mentions flexibility*
Self-efficacy	X	
Learning from failures		*May be too specific a skill for NCF*
Resilience	X	
Quality assurance		*NCF mentions measures to ensure the quality of the educational system not quality assurance as a skill to be taught to students.*
Reflection	X	
Evaluation	X	
Self-evaluation	X	
Time management	X	
Project planning	X	
Computational thinking		
Digital and programming skills	X	*NCF speaks more about digital literacy*
Entrepreneurship	X	

Appendix D – Coded Excerpts from Interview Transcripts

Table 7 Frequently used excerpts from interviews and assigned code

Frequently Used Excerpt	Code
"...you need to have time to learn, time to waste time learning, you know, and I think our generation isn't as fluent or let's say the younger generations with digital technology are much more, you know, efficient and fast than the older generations." – Industry Professional with Structural Engineering Background	IPSE1
"...building a frame structure. It's always the same frame structure you're always gonna look for the nodes between the frame in any program. It's the same thing, you know, and we're always gonna implement the same building codes and the same standards within the program, so there's all that commonality. It's the same analysis if it's being done with the same code of practices..." – Industry Professional with Structural Engineering Background	IPSE2
"...with every cycle... if you're doing material investigation and maybe bending something, now I know what material will do, but what will, let's say, the machine itself allow me to do? Now I know more about the material, more about machine. How do I marry one to the other? So, I think it kind of forms this circular loop. I would put them all under the umbrella of design knowledge, both of them. So, the design knowledge grows with every iteration and that's why I think design should be both sketching on paper and prototyping on working models. Kind of, it needs to come out. Then maybe comes, you know, digital modelling and evaluation. And then... it's tested. And then it's probably going to fail. Now we know, and then we go again. So, I think it's an iterative process, but they feed off each other." – Academic from FfBE	AFfBE1
"…most prototyping work, and even machine work, previously was manual, so you needed to have the manual skills to operate those machines and the manual way. It doesn't mean that we've automated completely the fabrication, and it doesn't necessarily mean that you don't need to have the skills and knowledge to operate those machines. Maybe not manually because you're not driving as used to done before with the wheels and you're driving the manual carriage, but the actual machining knowledge still needs to be there. You need to know what cutters need to be used. You need to know which feeds, the depth of cuts and everything. The software doesn't automate everything for you, so whilst the machines are controlled more digitally, you	AFoE1

still need to have the knowledge of the process then which supplements that. Obviously, in terms of skills, certain things like the ways in which parts used to be aligned before, there used to be a lot of skill to just set up the part onto the bed, to make sure there is very good alignment, etc. With the use of certain technologies that reduces because that type of manual intervention has been automated, so you have measuring vision systems, you have calibration systems between the machines themselves, which allow the machines to calibrate themselves automatically and therefore you don't need that memory interaction so much." – Academic from FoE	
"Let's put an example of a new device, OK? These are very dynamic, things change a lot, so you cannot say I want to learn, or I want to assess how well they know this machine. It takes it a bit on a higher level. You want to assess their ability to grasp new concepts, so it's a shift from teaching how to handle a tool, to teaching how to approach a new workflow." – D&T EO	DTEO1
"...light coding and so on, because it allows you to automate a lot of different things in your process, your day-to-day process. Something that would normally take you 3 hours of data input can now be done with a few clicks, an app or something. Even for information sharing with different parts of the group... it shows how important software is to efficiencies as well I think and that is probably one of the big things that's lacking, we only do a very basic amount of it..." – Industry Professional with Mechanical Engineering Background	IPME1
"I ask students to really understand the geometric logic of something they are developing, so once they fully understand, and we literally develop geometric logic as a step-by-step algorithm, you know, I start with… I don't know like a Polygon ABC, midpoint, maybe you know, connect… So, I tell them, develop an algorithm to the point where I follow line by line and I can actually, you know, develop that. Once we have that then we can use Grasshopper, you know, because quite often they get tangled up into using Grasshopper as a modelling tool, which it is not. It's modelling of logic or processes. So, this is where I kind of always… My focus is as I said, not aesthetics, not evaluation, but the process, design process itself and logic behind it." – Academic from FfBE	AFfBE2
"...there is a very vast range of new technologies which students encounter every day. They are rather new and emergent, and they are the future – like embedded Internet in devices, like digital manufacturing is also one of these areas, alternative technology, alternative battery technology, alternative energy." – D&T EO	DTEO2

"So, let's say 20 years ago, architecture was dominated by star architects. Zaha Hadid, Frank Gehry, like Bilbao Museum, you know, like aesthetics, iconic building, like star architecture and iconic building, and now the switch is more kind of grassroots level, bottom up. So, things like working with communities, working with participatory design, investigating material properties so materials would do what they're meant to do." – Academic from FfBE	AFfBE3
"… with AI and computer vision – any form of programming – the programming languages change or adapt. Even the simulation tools which we have available, the programming tools which we have available, the languages which we utilise, change, but at the end of the day, how you program doesn't change." – Academic from FoE	AFoE2
"It doesn't mean that because we encourage critical thinking, the critical aspect, the scientific and science thinking we don't encourage the arts, the open thinking or creativity. On the contrary, for me they are one and the same. We can't have one without the other. They're both very important to form the engineer of the future. The technologist of the future." – Academic from FoE	AFoE3
"I'm the type of person who would only learn something after quite a good number of mistakes at trying to do it. But then I would know it, because during that process I would have gotten to know better why or how to do it properly and probably I would have searched couple of times what it is that I would have wanted to know." – D&T EO	DTEO3
"I never teach students how to use a 3D printer. That's not my aim. I set up a project where they understand that 3D printing would be an ideal way to solve this problem. So should they need to use a 3D printer, there is when I start teaching how to use a 3D printer or what a 3D printer is. So, they have a general knowledge of what it is, but then I do not make students use a 3D printer. They need to feel the need to use the 3D printer, so then they'll obviously need to know how to use the software, so you know, having students identify the need and then accepting their questions and answering their question basically." – D&T HoD	DTHoD1
"I think AutoCAD is really useful for production of drawings, but not for the design development… certain tools are actually detrimental for creative thinking and design thinking because a lot of times... they're easy to learn, so before it was like Maya and 3DMax, very difficult to learn, the learning curve was very high, so building a model and developing the project through sketches and physical models was the way forward. But then you'll see you	AFfBE4

kind of work with the site, you understand the scale… You work with the physical model, your working model, you understand the curvature, you understand the materiality, you understand gravity – that's probably the most important aspect. When you switch... curvature disappeared because SketchUp doesn't allow you to do curves. So, then what happens is what is considered as instrumental knowledge, the knowledge of the tool, caps your design skills. " – Academic from FfBE	