Chapter 10
Doing

Skills, Knowledge, and Understanding in Conceptual, Theoretical, and Practical Contexts

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Introduction

Doing sits at the very heart of technology education. It is fundamental. To omit doing is to tell only half of the story of technology education and, in practice, would limit pupils to learning *about* technology, rather than learning to become technologists. Doing, however, is a very broad notion and could be understood in any number of ways. For example, the very agency that pupils and teachers bring to a technology classroom—or any classroom for that matter—comprises forms of doing. When pupils undertake desk research into different material properties to make design decisions, they are, arguably, cognitively engaged in the act of doing things. The risk here, it seems, is that the notion of doing might be so broad as to tell us nothing meaningful about learning in technology education. A fundamental aim of this chapter is therefore to understand "doing" in the context of this subject area, its conceptualization in curricula, and ultimately its role in shaping how pupils think, understand, and become more technologically capable in the technology classroom.

The idea of "doing" in technology education is not new. In some countries, the formalization of technology into a modern curricular subject happened in response to shifts in agricultural needs; the imperative for people to become better at its many practical processes (or wider manual skills and processes seen as important, often for boys to develop). At the time, this served the obvious requirements for food production and supported wider societal and economic development. Since that time, there has always been some level of socio-technical influence on what pupils "do" in technology education. On the one hand, this has granted a pervasive and endearing authenticity to the subject. But on the other hand, it has, in time, led to tensions in how we position technology education—and how people value notions of doing. In countries like Scotland, where the lineage of technology education has an agricultural dimension, the forms of doing most valued were those that reflected and cultivated important agricultural skills. In the United States, manual arts sought to both develop manual skills and more fully engage boys in schooling. Over time, this has changed. The subjects of contemporary technology education are not designed, or intended, to prepare pupils for specific jobs as they once were. They provide more holistic learning as academic rather than vocational qualifications, but nonetheless retain an important level of authenticity. It is not hard, for example, to recognize the authenticity in learners using the same 3D modeling software as would be found in industry, or the same machines, processes, and manufacturing technologies. This will remain immensely valuable. But what pupils are doing in technology education moves beyond vocational utility; something that is not always recognized or sufficiently understood. Impoverished and naïve assumptions might see doing as simply "making stuff," which is also to de-value the rich and fundamental ways in which pupils make meaning and develop their own technological knowledge and capability.

So, what forms of doing does this chapter regard as important for the thinking and practice of technology education? This chapter proposes one way of thinking about doing that aligns it with practical, experiential forms of learning in the subject and is based upon three key starting points. These serve as conceptual anchor points and will frame discussion and considerations made throughout the rest of this chapter. The first is that it is not possible in practice to separate thinking from doing, although the philosophical discourse offers rich insights and perspectives on the nature of the mind–body relationship. Powerful forms of doing in technology education bring together the hand, the head (and the heart). The second starting point is that to be valuable for technological knowledge and capability, doing must have some form of association with materials. This does not preclude the other essential and "non-material" forms of doing in technology education classrooms, but it does require that materials occupy particular roles in key aspects of pupil learning. They are part of the practical contexts in which pupils think and learn. The third and final starting point argues that effective forms of doing should allow pupils to learn to create and/or understand technology. As creators of technology, pupils engage in different forms of doing to move from concept to technical solution. To understand technology, pupils can use forms of doing to develop their conceptual knowledge and understanding through modeling, exploration, and reflection. Indeed, modeling as a form of doing can allow pupils to build toward equilibrium (Seery, 2017) by iterating between their own cognitive model and its material analogue. In a self-supporting way, as pupils gain experience through doing, they become yet more effective in both creating and understanding technology. This is, in the experiential sense, a rich form of learning-by-doing. For the purposes of this chapter, and from this point forward, "doing" will therefore be understood in terms of these three starting points: its inseparability from thinking and materials, as well as for its dual purposes of creation and understanding. What makes it distinct from other forms of doing is that by engaging with it, pupils are better placed to develop important forms of technological knowledge that cannot be acquired in other ways.

The remainder of this chapter comprises four sections. Collectively, these seek to develop an understanding of doing, and approaches to foster it, that have value for learning and teaching in technology education. This is done with particular attention to the three key starting points. To better understand the role of doing in developing technological capability and ways of thinking, the first section considers the relationship between doing and technological knowledge. In doing so, the three key starting points are also fleshed out to paint a fuller picture of what powerful forms of doing might look like for technology education. The second part explores how ideas of doing represented and understood in curriculum policy, one of the core message systems in education. The third part considers the role that craftsmanship plays in doing and the influence it has on the less cognitive aspects of learning including pride and ownership. The final section exemplifies doing at the classroom level from the perspective of pedagogy. It begins by thinking more broadly about pedagogy and doing, before presenting two different teaching and learning scenarios that were purposefully designed to foster learning through powerful forms of doing. Collectively, it is intended that these four parts provide a basis for critically reflecting upon how doing is understood and supported technology education. The chapter concludes by summarizing key ideas and invites readers to critically reflect on these as part of their own thinking and professional practice.

Doing, Technological Knowledge, and Purpose

One reason why it is important to hold onto more developed ideas of doing technology education is that it affords greater agency in how teachers foster pupils' technological knowledge. It is not actually possible to separate the doing in technical activity from the knowledge it gives rise to, but it would be folly to think this serendipitous. Two related areas of thinking allow this to be explored more fully. Each of these areas unpack a little more of the three key starting points. The first is that technological knowledge can be understood as something that simultaneously shapes and arises from technological activity. The second is that if pupils are to create technology, then they must have opportunities to create that which extends or enhances human capabilities in some way.

The nature of technological knowledge has received significant attention in the technology education literature. This has been fueled by both the intrinsic fascination of the idea of technological knowledge, as well as its potential for shaping wider understandings of technology education. Among other things, it is understood to involve conceptual, procedural, declarative, and conditional dimensions (Buckley et al., 2019), each of which may take more explicit or implicit forms. The way in which these are defined varies within the literature and, in practice, they are often heavily interdependent and can be challenging to separate. Conceptual knowledge is typically thought of as knowledge of the nature of the relationships between different things, such as different parts of a technical system. In developing procedural knowledge, a pupil will know the steps involved in carrying out different processes to achieve particular outcomes, while declarative knowledge is descriptive knowledge of things that remains fairly constant over time. Conditional knowledge occupies a form of executive or metacognitive role and involves knowing when is best to use other forms of knowledge. Notably, these forms of knowledge are not unique to technology education, but the purposes, contexts, and ways in which technology education pupils develop them often are.

These ideas, and the wider thinking about technological knowledge, have their origin in the concepts of epistêmê (knowledge), technê (skill), and phronēsis (practical wisdom and judgment), first set out by early Greek philosophers, including Aristotle and Plato. On one level, these appear cogent facets of technical activity and, therefore, of "doing." But at a deeper level, there are enduring complexities about the nature of technological knowledge in technology education. It bears an elusive quality that can make it hard to get at. This is because important dimensions of technological knowledge are often implicit. They are embedded in, and arise from, technological activity itself—from the very material forms of doing that this chapter explores. Ropohl (1997) provides some fascinating insights into embedded forms of technological knowledge and identifies, among other things, technical laws that hold true because they work in practice rather than necessarily resting upon scientific foundations. This being said, it is often the case that this knowledge, as critical as it is, cannot always be readily captured in writing, or comprehensively externalized during learning and teaching. Rather, it is developed and applied within the experiential and material learning of pupils. But how is it that "doing" in technology education differs from "doing" in other subjects, such as art? And what does it mean to be a creator of technology?

When material forms of doing are thought of, the imagination conjures up a range of possibilities. Painters and sculptors engage in doing, for example, just as a mechanic or gardener might. What is interesting, however, is that some of these people are naturally thought of as being more "technological" than others. A painter employs the materials of canvas and acrylic, and uses hand tools such as the brush and palette knife to manipulate them, but is this form of doing different to that which would be fostered in a technology education classroom? On one level, no. An artist is not typically thought of as a technologist, but they nonetheless draw upon skill and judgment in the use of tools to manipulate materials. Such similarities are perhaps most stark for artists who sculpt in metal. In this case, the same processes, joining methods and materials are at play as would be found in a technology education classroom. It would hence be fair to say that such artists are engaging in very "technological" ways of doing which allow them to develop and apply practical forms of knowledge. On another level, however, it is different. This difference lies not with the identifiable features of doing per se, but rather, with the underlying purposes and volition that drive it. In art classrooms, these ways of doing support pupils to learn about and create art, and what is created serves artistic, aesthetic, or cultural functions. In technology education, valuable forms doing must include those that allow pupils to learn about and create technology—that which functions to extend or enhance human capability in some way. From this, two important points arise. First, that it is important to give consideration to the types of tasks and briefs that pupils will work on in technology education. Asking pupils to design and make a vase might be very different from asking pupils to design and make something that improves a household process for people with reduced strength in their hands. Second, the different purposes underlying the activity of art and of technology mean that some types of knowledge and understanding become more prominent for how pupils think about and understand these respectively. Knowledge of the ergonomic interactions of hand grip and movement is likely to be far less important to vase design, whereas the interaction of aesthetic factors, influences, and interpretation is less important to supporting people with reduced strength in their hands. It is for these very reasons, that more reductive ideas of doing as simply making things are insufficient in helping to understanding something more of the nature of technology education.

"Doing" and the Technology Education Curriculum

Despite being a comparatively young subject, virtually all curricula include something that can be identified as technology education. Further to this, it is unsurprising that ideas of doing can be found throughout these. As already noted, it reflects something of the fundamental nature of the subject and the central role of materials. At the very least, any curriculum must do two things: (1) identify what is deemed valuable for pupils to learn for a particular country or region, and (2) organize what is identified in some way. The particular ways in which a given curricula conceptualizes and positions "doing" arise from the cultural, historical, and socio-technical influences of that country or region. Some of the more prominent of these influences include product design approaches, manual craft and skills development, cognitive processes and application, and the role of engineering in the context of STEM subjects. These influences are not discrete. They not only give a sense of what is regarded as important to learning but also evolve and change over time as some influences work to displace others.

In England, doing is most prominently articulated through design and make and is heavily influenced by product design. As with other curricula, it is linked closely to processes of creativity and creative thinking. Open-ended, design-based contexts for doing promote rich learning opportunities. However, these contexts can displace other "doing" processes such as discrete troubleshooting and structured fault finding that hold potential for understanding technology, but more often constitute part of vocational programs of learning. Some curricula, such as the new Curriculum for Wales, specifically identify intellectual processes such as modeling or prototyping, sometimes in the context of systems and engineering, and sometimes in the context of product development or technical outcomes. When tool use is made explicit in curricula, it is typically done so in relation to health and safety. Sometimes, curricula will organize descriptions of learning to reflect an expectation that pupils become more accurate, accomplished, or independent in what they do, or can apply learning in other, less familiar contexts.

Many countries have been influenced by a rich history of craft traditions such as Sloyd, an educational movement focused on craft skills that originated in Sweden. Hallström (2017) analyzes Educational Sloyd in detail noting its influence on technology education and the many shared technical and structural characteristics found with technology education classrooms more widely. It is centered upon apprenticeship models of learning and instruction encompassing "demonstration" which is regarded by McLain (2018) as a signature pedagogy in technology education. As a form of doing, Educational Sloyd promotes the practical skills, judgment, knowledge, and patience required by pupils as creators of artifacts and technology. Hallström recognizes that it brings together hands, head, and heart. Although its influence is still found in several curricula, including Finland and Scotland, these types of craft skills have sometimes been displaced over time by systems, electronics, and engineering (which could be considered forms of "high" technology). Recent curricular thinking around technology education in the United States, for example, makes arguments for adopting a more engineering-centric approach to technology education in the context of STEM and integrated STEM education. This situates some of these important forms of doing within engineering ways of thinking which could be seen by some as a structural move away from technology education as a curricular area. In practice, this curricular displacement might mean that doing for the purposes of understanding technology (e.g. modeling of systems, interactions, interdependences) becomes more prominent, where doing for the purposes of creation (e.g., the application of practical skills) was historically dominant.

There is a sense then that doing can be situated differently in curricula. While it is highly likely that curricula rich in opportunities for practical learning will bring value to pupils generally, few—if any—capture the more developed ways that doing can be understand in technology education. Learning, by its very nature, is complex, mutable, and heavily contextualized. Language, in the context of curriculum, is necessarily limited in its ability to capture learning and the curriculum itself cannot be conflated with pupil learning. How, for example, can the more implicit forms of knowledge that pupils gain through doing in technology education be reliable captured—even though we know them to be valuable? It is in light of this that more developed ways of understanding doing become important for teachers as they think through curriculum, assessment, and pedagogy and bring the curriculum to life for pupils in technology classrooms.

Doing and the Human Dimension of Learning

Up until this point in the chapter, consideration has been given to the nature of doing from a range of perspectives, including its characteristics, its relationship with knowledge, and its place in curricula. It is hoped that this has captured the importance of thinking about doing as much more than simply making things. Through material interaction, it plays a fundamental role helping pupils develop particular kinds of technological knowledge and, as creators of technology, it fosters their technological capability. But this tells only part of the story. It is important to also understand doing from the perspective of the pupils themselves. Taking time to do so reveals some of the distinctly human qualities that doing can bring to pupil learning in technology education.

It has been shown that doing in technology education can serve different purposes. Whether these relate to modeling, understanding, prototyping, or creation, the interaction with materials will demand particular skills and often involve the use of tools. What is argued here is that doing in technology education, regardless of its purpose, embodies *craftmanship* in the rich and nourishing sense described by Sennet (2008). In his exploration, Sennet argues convincingly that craftmanship is misunderstood, and extends beyond artisanal notions to a whole range of different activities and, in terms of this chapter, forms of doing. There is craftsmanship in science, just as there is in writing, musicianship, and jewelry making. Against this, he draws out a number of assertions. One is that craftsmanship is concerned with skill and the desire to do something well for its own sake. In other words, for its intrinsic worth. Developing such skill takes time but engenders a sense of pride and accomplishment, both of which can be powerful influences on pupil learning and motivation. Another assertion is that craftsmanship links hand and mind in ways that cannot otherwise be achieved. This very much reflects the idea that in powerful forms of doing, thinking and doing are inseparable and enable certain aspects of technological knowledge and capability to be developed. It is not possible to become competent at modeling something only by reading about it. Notably, it also reflects the unison of hands, head, and heart found in the ideas of Education Sloyd (Hallström, 2017).

But Sennet also points out that sometimes, technological advancements can make the relationship between hand and mind a little more distant. He cites the introduction of CAD software and describes how the features and capabilities of the software lead to designer thinking differently about what they are designing. He notes that the ability to readily change things reduces the consequences of design decisions and means that things can ultimately be less well considered. Furthermore, he recognizes that the lack of materiality and shortcutting of the manual creation of plans means that the knowledge and understanding of the designer are different and not as engrained as it might otherwise be. It is noteworthy that in Scotland, the expansion of CAD modeling capabilities in secondary schools was accompanied by the removal of the assessment of manual drawing skills in national examinations. While the reasons for this are unclear, it led to a profound shift in what some schools saw as valuable learning and many departments have all but removed manual drawing lessons. Where schools have retained it, it is because teachers maintain that it allows pupils to understand drawings and technical relationships in ways that they do not with 3D CAD modeling alone. This highlights some of the less obvious effects that socio-technical influences can have on what it is that pupils do in technology education, and being aware of the consequences for learning is important when creating lessons in technology education.

In thinking about more developed ideas of doing, it is therefore necessary also to think about more developed ideas of craftsmanship. There is a tactile and human dimension that can foster a strong sense of pride in pupils and an opportunity for teachers to help them develop a sense of learning to do something for its intrinsic value rather than to meet a particular learning goal. Craftsmanship should not only be recognized when pupils create technology using hand tools in practical workshops but should be recognized and fostered in all material forms of doing.

Doing and Pedagogy

Pedagogy is where teachers integrate complex areas of expertise, including subject matter, learning theory, beliefs, values, personal practical theories, contexts, and their own pupils. Done well, it is where this expertise gains classroom traction for pupil learning, and it is essential that it is both adaptive and evidence-informed. Influenced by the understanding of pedagogical content knowledge developed by Shulman (1986), this chapter adopts the view that, rather than being a generic set of strategies and techniques, pedagogy is shaped by the epistemological and ontological nature of that which is being taught. In other words, it is not possible to determine how something might be taught effectively, without first understanding the nature of the subject matter and the purpose of learning. This is particularly significant given the vast range of different types of subject matter that characterize contemporary technology education subjects. It is thus complex and subject specific. There is no single "pedagogy for doing," and simply getting pupils to make things will fail to properly develop their technological knowledge and capability.

In reality, pedagogy around doing has to pay attention to a range of different factors. These can include how different skills are sequenced and organized, or how to make explicit from the outset those things that should become more implicit for pupils as their skills develop. It might involve thinking through the relationships between different types of knowledge in regard to the concepts, ideas, and processes in the curriculum—and whether the associated pedagogy is likely to promote desirable forms of learning and understanding. It may also have to support pupils in how to move their understanding between conceptual and practical contexts. In designing learning activities for pupils, are opportunities included for them to create and understand things that are distinctly technological, rather than artistic or cultural? When is it desirable to get pupils to model something in three dimensions to understand its technical relationships, rather than only exploring it conceptually? The most important point here is that it is not so much a case of identifying a "pedagogy for doing," but rather identifying where and how doing should be made part of subject pedagogy.

To further explore this at the level of classroom practice, two real-life examples of pedagogical approaches from secondary technology education are discussed. In different ways, they address and develop aspects of doing in technology education as something that is inseparable from materials and thinking, and which allows pupils to create and/or learn about technology. The first example, "Tangible Ideation," considers how doing might be used differently in the process of concept generation. It questions the almost ubiquitous role of sketching as a means of leading idea generation. The second example, "Material Knowledge," focuses on the implications for pupil learning of different types of materials knowledge. Technological knowledge is used in and arises out of technical activity which means that doing has a significant role to play. This example challenges some of the assumptions that can be made about the forms of knowledge pupils engage with through doing. It is hoped that both of these examples will provide some insight into how doing can be considered as part of pedagogical reasoning.

Pedagogy Example 1: "Tangible Ideation"

In technology education, design occupies a fascinating place whereby it is both subject matter and pedagogy. This requires that teachers pay attention to its affordances and limitations as a teaching method as well as how pupils might best understand and use it. Central to this are questions about the nature of learning. How pupils are supported to make meaning, to develop technological knowledge and capability through doing must therefore be part of this thinking.

A process common to all design activity is ideation, sometimes also referred to as concept generation. It is an intellectually challenging process to do well. More often than not, when people think about pupils generating design ideas, they think of sketching. Sketching provides a low-resource, rapid, responsive, and iterative means of developing and communicating design ideas and thinking and is used by designers the world over. It remains a central means of working through design ideas and supporting this type of design thinking. That being said, there may be more to think about from a pedagogical perspective. If doing is to be understood as something that is inseparable from thinking, involves materials, and supports the creation or understanding of technology, reliance upon only sketching as a means of ideation becomes limiting. In this context, sketching is a purposeful form of abstraction and representation. Yet, for learners, it can separate materiality and thinking and its efficacy and value rests heavily upon the spatial ability, sketching ability and confidence of individual pupils. If pupils feel that they are struggling to represent and externalize their ideas through sketching, they might modify or simplify their candidate ideas to succeed in representing them. Furthermore, if sketching is sequenced so that it always precedes modeling, it can make it harder for pupils to understand the interrelationships between different two-dimensional forms of abstraction and their corresponding three-dimensional material representations.

In response to this, a pedagogy for "tangible ideation" is now described in which the iterative exploration of design ideas is driven by tangible materials over sketching. Rather than omitting sketching from the ideation process, this approach repositions it by foregrounding the manipulation of materials as the primary means of developing design ideas. Just as would be the case if design ideas were sketched, pupils require a sufficient understanding of the design brief or problem before they begin. Rather than starting idea generation with paper and pencil, pupils are given a range of different soft modeling materials, tools, and means of joining parts together. The choice of materials and tools will be influenced by the nature of the brief and the pupils themselves but could be as simple as card and paper. Demonstrations may be required in the early stages to ensure pupils can safely and effectively manipulate tools and resources. As with sketching, the purpose of this process would be to generate different design ideas, but pupils doing this for the first time might associate modeling with expectations of a "finished" prototype rather than seeing it as an exploratory and creative process. Discussing this explicitly with pupils at the outset is important to empower risk-taking and would be one of several decisions taken about how the overall process would be framed. Pupils may, for example, generate more than one possible design idea or move through phases of modification and development of a single concept.

Regardless of the process, there are several potential benefits that "tangible ideation" could bring to learning. It provides a space in which pupils can continually interact with their developing ideas in both tactile and cognitive ways, helping to break down potential divides that emerge between the conceptual and practical contexts. It retains materiality and reduces abstraction. The free rotation and reorientation of parts during the development process allow pupils to understand the spatial and configurative features of their solution differently from that which is afforded through sketching alone, or even 3D CAD modeling. As a form of three-dimensional modeling, it can also support mechanistic and technical reasoning, helping pupils to build from their activity the forms of technological knowledge important to technological capability. Notably, a study by Welch (1998) explores in detail pupils modeling processes during design and advocates opportunities for them to model ideas earlier in the process. Different stages in tangible ideation can be captured in a variety of ways, including photographs, sketches, annotations, and the physical models themselves.

As an example of "doing" in the way that this chapter encourages, this pedagogical approach does three things. First, it connects thinking more directly with materials. Second, it helps pupils learn about creating technical solutions, and, third, it allows them to understand potential solutions in ways not possible from sketching alone. It is important to stress that this approach is not intended to replace sketching as a method for idea generation, but rather provide another pedagogical approach that could be used at key points to enrich pupil thinking. It is more time and resource dependent than sketching and, similarly, is not immune from the effects of cognitive fixation.

Pedagogy Example 2: Material Knowledge

Technology education is a very broad subject that encompasses a great many concepts, ideas, skills, competencies, values, and dispositions. To complicate things further, pupils can come to know about and understand these things in different ways—some of which are more valuable for developing technological capability than others. It may be the case, for example, that pupils learn about Light Emitting Diodes in both their science class and their technology class. However, in the science class, learning may focus more upon p-type and n-type materials, silicon junctions, photons, and wavelengths of light. In the technology class, learning might focus more upon operating parameters, integration with circuits, and so forth. Without careful attention to the types of knowledge pupils require, difficulties can arise in pupil learning, and this is particularly true for "doing." One example of this can be found when pupils make design decisions using either partial or misaligned knowledge of materials. The following scenario provides a starting point for thinking this through.

> *A class of twelve and thirteen-year-old pupils have undertaken online research into the properties of steel to support the later stages of a design project in which they are, for the first time, designing and manufacturing a technical solution that incorporates sheet steel. The teacher moved around the class engaging in formative dialogue as pupil worked to finalize their design ideas. On several occasions, this dialogue prompted pupils to reflect on the feasibility of certain aspects of their design given the material they are working with. This helped concepts to be further refined before pupils thought through the tools, processes, and sequencing that might be used to manufacture their solutions in the workshop. After having read the pupils plans for manufacture, the teacher found that they were struggling to match particular tools with the types of cuts and joints that their ideas required. The teacher therefore undertook some additional work with the class on different metalwork tools and processes relevant to their design ideas.*

Scenarios like this may be something that teachers of technology education have experienced and worked through with their own classes. Despite the fact that pupils have spent time learning about mild steel, they are designing shapes and perimeters that they simply would not be able to cut from this material and, furthermore, are struggling to know which tools and processes would allow different parts to be made. The issue is to do with the *type* of knowledge pupils have of materials. The knowledge of steel they developed from internet research did not arise from practical activity. Pupils had no direct, experiential knowledge of what this material was like, what it felt like, how it responded to different tools and processes, and what its practical affordances and limitations were. Much of this knowledge would be closely linked to pupils' senses and may be quite implicit. In a sense, the type of knowledge they developed about steel was relevant, but not of the type they required to make meaningful design decisions. It was insufficient.

One way of addressing this was to think through where and how forms of doing could be integrated into the pedagogical approach to allow pupils to build up a more aligned and usable knowledge of materials. Rather than experiencing materials through design then make, the class was set the challenge of building up a knowledge base about materials that they could use to inform ideation before they began designing. Following the requisite inputs on proper tool use and health and safety, pupils worked in small groups and moved through a series of practical stations that were set up in the technology workshop. Each station was centered on a practical process with different materials, such as wood and metal, that pupils had to undertake and reflect on using a series of questions and prompts. One station asked them to cut parallel lines in sheet material, another asked them to fold along a line using different methods, and another asked them to create a curve in the perimeter. The purpose of these exercises was not to develop practical skills but to develop particular types of knowledge about materials. The questions and prompts asked pupils to rate how easily they could carry out the process, how many times they might be able to do it before they got tired, which approach or tool was more effective for different materials, and so forth. They were also asked to speculate about where they might use different approaches and to reflect openly on anything else they found significant during each challenge. The findings from the class were averaged and shared back with pupils to provide a class knowledge base about materials.

As a pedagogical approach, this enabled pupils to develop a more aligned and usable type of materials knowledge. During both the ideation phase pupils could account more directly for the nature of the materials involved and, in planning for manufacture, pupils were able to reason far more independently about the most appropriate tool to use for particular features of their design with less reliance upon formative support from the classroom teacher. This example underscores the need to think carefully about how pupils can best develop and apply important forms of knowledge as part of doing in technology education.

Summary

Technology education continues to offer pupils uniquely rich and varied learning experiences that encompass a diverse range of skills, knowledge, and understanding in conceptual, theoretical, and practical contexts. In this sense, it is perhaps unlike other subjects. Across all of this, doing plays a fundamental role in helping pupils to develop their technological knowledge and capability. While forms of doing can be identified in all technology education curricula, how it is positioned and represented can vary and is shaped by ongoing socio-technical and political influences of different countries and jurisdictions as they attempt to capture what is valuable for pupil learning. Here it is argued that all technology education curricula will require that teachers and student teachers identify and nurture the most valuable forms of doing to support pupils to develop their technological knowledge and allow them to move beyond only learning *about* technology.

A central aim of this chapter was to think through how particular forms of doing can be understood for technology education so that this is not left to chance in practice.

By way of addressing this aim, three starting points were given which—it has been shown—bear quite complex interrelationships. The first point was that doing cannot really be separated from thinking. Indeed, in technology education, pupils must think carefully about how they engage in particular forms of doing, and the very act of doing itself gives rise to new knowledge, understanding, and ways of thinking. There is a reciprocal quality to this which must be carefully harnessed to ensure that it strengthens, and not weakens, the links between hand, head, and heart.

The second starting point argued that powerful forms of doing in technology education are related in some way to materials. Just as doing is inseparable from thinking, technology is inseparable from materials. This is significant because, for pupils, it is material interaction in technical contexts that unlocks the door to other forms of technological knowledge, understanding, and reasoning that they cannot otherwise develop. It may not be in a form that can be reliably described in writing, but it can dramatically alter the design and construction decisions that pupils make as creators of technology. In this same area, the craftsmanship that is so readily associated with material forms of doing can provide pupils with a sense of connection, pride, and a recognition of the intrinsic worth of doing things well and to a high standard. The development of craftmanship in this sense applies to all forms of doing encouraged in this chapter.

The third starting point stated that valuable forms of doing are those that allow pupils to understand, and/or learn about technology. Reflecting on this in practice requires student teachers and teachers to think about not only where and when pupils might engage in different forms of doing, but also how technology is understood in the context of their subjects. Where is it necessary for pupils to model or simulate something with material forms of doing in order to better understand and reason about it? Where should opportunities be given for pupils themselves to become creators of technology? Are those things that pupils create actually technological and when, if at all, might this be important in their learning?

Much of what this chapter explores can be implicit in the practical, day-to-day learning and teaching in technology education classrooms. Perhaps, there are ideas or perspectives here that could become a more explicit part of how teachers think through pedagogy and consider how different pedagogical approaches influence the types of knowledge and understanding that pupils cultivate as part of their learning. While this is hopefully valuable for student teachers and teachers in terms of professional practice, it may also be necessary to develop pupils' explicit awareness of valuable forms of doing if the benefits to learning are to be maximized.

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