Towards a three-part heuristic framework for technology education

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Abstract

There is not one single global version of technology education; curricula and standards have different forms and content. This sometimes leads to difficulties in discussing and comparing technology education internationally. Existing philosophical frameworks of technological knowledge have not been used to any great extent in technology education. In response, the aim of this article is to construct a heuristic framework for technology education, based on professional and academic technological knowledge traditions. We present this framework as an *epistemological tripod of technology education* with mutually supporting legs. We discuss how this tripod relates to a selection of epistemological views within the philosophy of technology. Furthermore, we apply the framework to the Swedish and English technology curricula, to demonstrate its utility as an analytic tool when discerning differences between national curricula. Each leg of the tripod represents one category of technological knowledge: (1) technical skills, (2) technological scientific knowledge and (3) socio-ethical technical understanding. The heuristic framework is a conceptual model intended for use in discussing, describing, and comparing curriculum components and technology education in general, and potentially also as support for planning and conducting technology teaching. It may facilitate common understanding of technology education between different countries and technology education traditions. Furthermore, it is a potentially powerful tool for concretising the components of technological literacy.

Keywords Technology education · Technological knowledge · Philosophy of technology · Technological literacy

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Introduction

From the 1980s onwards, countries all over the world have introduced technology as a school subject. This relatively young subject has epistemological roots in such diverse traditions as craft, sloyd, industrial arts, natural and social sciences, and engineering. As a result, technology education struggles with its identity and the central epistemological concerns of the subject (de Vries, 2011, 2017; Hallström et al., 2014). Both technology curricula and the implementation of the subject therefore look very different internationally. In some countries it is integrated into science subjects (e.g. in Danish primary education), while in others it is separate. In some countries it is a mandatory subject, and in others it is optional. It also varies considerably with respect to content: Finland's "technical sloyd" has a strong focus on craft-related skills (Finnish National Agency for Education, 2014); England's "design and technology" is based on the design process (Department for Education, n.d.); and Sweden and New Zealand have broad technology subjects, intent on covering engineering skills and environmental issues as well as the history and sociology of technology (Ministry of Education, 2018; Skolverket, 2020). The subject of technology may consequently include a variety of subject matter and curriculum components, and may be labelled differently, depending on the country and the part of the world (Jones et al., 2013).

The global differences in form and content in technology curricula and standards mean that individuals in different countries may have diverging ideas about what technology education in school is or should be. This leads to difficulties in discussing and comparing technology education internationally. In addition, there might also be discrepancies at a national level or even in local schools, since teachers, principals, and researchers may have diverse views of what technology and technology teaching are (Doyle et al., 2019). One reason for this is that, unlike many other school subjects with longer traditions, such as mathematics and science, the subject of technology seems to lack a clearly-defined and coherent subject philosophy (e.g. Ankiewicz et al., 2006; Chesky & Wolfmeyer, 2015). There is thus a need for a comprehensive framework to understand, compare and discuss similarities and differences in subject conceptions, thereby laying the foundations for a subject philosophy of technology education.

Existing frameworks of technological knowledge from the philosophy of technology have not been used to any great extent in technology education, for example, in curriculum design, probably because most of them were not developed for technology education. The New Zealand curriculum is one exception (see Compton, 2019), where Ropohl's philosophy was used as a foundation in the development work. Another is technology education in South Africa, where Mitcham's (1994) fourfold model of technology was used for the evaluation and development of technology teacher education and school technology education (Ankiewicz, 2013, 2015). In contrast to the prominent features of previous frameworks, we believe that in order to further understand and describe the school subject of technology, we need to consider which *traditions* contribute to technology education and what kind of *knowledge* that forms the epistemological foundation of the subject. One way of doing so is to develop a heuristic framework related to these two aspects, thereby encouraging the subject philosophy of technology education to develop further. Ideally, such a framework should be understandable and useful for researchers in technology education, as well as for teachers. Furthermore, it should serve as a tool for planning and evaluation, as well as for comparing textbooks, curricula and other texts relating to technology education. Preferably, it should also be

graspable for technicians, engineers, historians of technology and other interested parties working outside the school context, simplifying communication between technology educators and technology practitioners.

In response to this challenge, the aim of this article is to construct a heuristic framework for technology education, based on professional and academic technological knowledge traditions. The utility of the framework in comparison with the most commonly used existing frameworks for technological knowledge (e.g. Vincenti, 1990) and technology education (e.g. Ankiewicz, 2015) lies in providing a categorisation system for technological knowledge in relation to (historical) traditions of technology and technology education. It will make comparison of curricula and discussions about learning objectives more to the point. We thus present this framework designed as an *epistemological tripod of technology education* with mutually supporting legs, and discuss how this tripod relates to a selection of epistemological views or frameworks within the philosophy of technology. Furthermore, we apply the framework to the Swedish and English technology curricula, to demonstrate its utility as an analytic tool when discerning differences between national curricula.

Background

Technology and technology education

The term “technology”—as used in everyday language—refers to a concept that is difficult to define or even describe. Hughes (2004) writes: “Technology is messy and complex. It is difficult to define and to understand. In its variety, it is full of contradictions, laden with human folly, saved by occasional benign deeds, and rich with unintended consequences. [...] Few experienced practitioners, historians, and social scientists try to inclusively define technology” (pp. 1–2).

Many attempts to define technology focus on technology’s purpose of satisfying human needs and fulfilling wishes (e.g. Lindqvist, 1987). This strategy inevitably leads to very wide views of technology, including not only what has traditionally been referred to as technology (engineering, industrial manufacturing, design and construction of buildings and artefacts, computers and their programming, etc.), but also other human endeavours that have seldom been regarded as technology (such as cooking or agriculture). Technology is a varied set of phenomena that has developed throughout the existence of humankind. Its development has taken place without any centrally decided plan. As a result, the use of terms such as *techne*, *technology*, *technique*, *engineering* and *industrial arts* has varied not only over time, but also between disciplines, between countries, and between authors (Mitcham & Schatzberg, 2009). The term “technology” is ambiguous, to say the least.

Technology in schools is somewhat easier to pinpoint, given that it is governed by official documents such as curricula, standards and syllabi. While the purpose of technology is, as mentioned above, to solve problems and fulfil wishes through the creation and use of artefacts, the purpose of technology education is rather for students to learn technology (de Vries, 2016). Technology and technology education thus have quite different rationales. In addition, the content of school technology is limited in scope when compared with technology at large; it cannot possibly include more than a few selected themes out of the wider field of technology (Norström, 2016).

The aspects of technology that have been included in technology subjects vary between countries and over time, as noted above. The fact that computer programming is a more

common subject content today than it was in the 1980s is hardly surprising, for example. One thing that typically characterises technology in schools around the world is that it is a multidisciplinary subject (see e.g. the syllabi of Sweden, England and New Zealand and the overview by de Vries, 2012). Fulfilling the stated purposes of technology education therefore requires a “broad spectrum of technology” to be addressed (Svenningsson, 2019, p. 13).

Technological knowledge

When discussing what technology and technological knowledge are, a common starting point is the declaration that technological knowledge is not the same as—or necessarily derived from—natural science knowledge. For example, Ropohl (1997) argues that “technology is a genuine kind of knowledge rather than ‘applied science’” (p. 65). Further, technology is generally described as what works and what is useful, while science strives to find general laws and establishing facts about natural phenomena.

Technological knowledge—knowledge within and/or about the technological domain—has inherited the vagueness of technology itself. In Mitcham’s (1994) fourfold description of technology as *object*, *activity*, *knowledge*, and *volition*, the knowledge component essentially refers to any knowledge that is useful in technological activities wherein technology is used or produced. Hence, technological knowledge in this model includes the craftsman’s abilities as well as the engineer’s mathematised, science-based methods and the assembly operator’s skills, based on standardised procedures. The skills, abilities and knowledge become technological through their inclusion in a technological context; they are not distinguished by methods, tools or means of justification.

Numerous classification systems have been developed to be able to analyse technological knowledge in more detail. They differ with respect to the grounds on which the classification is made and where they draw the limits for technological knowledge (for an overview, see Houkes, 2009). Vincenti (1990) divides technological knowledge into different categories based on the parts of an engineering design process in which it is used. Hansson (2013) categorises it according to how it is learnt and justified. Ropohl (1997) uses a less rigorous method, whereby some categories (technical rules, technological laws) are defined according to the means of justification while others (functional rules, structural rules) are based on their use. de Vries (2003) has created a system that is based on the notion of technical artefacts having a dual nature that includes physical and functional aspects, and their interaction. Only two of the systems mentioned, Hansson’s (2013) and Ropohl’s (1997), were explicitly created for use in the educational field, but they have not been used in any notable sense in the work of writing curricula or textbooks. Hansson’s system is confined to knowledge and skills used in technological construction and development, while Ropohl’s also includes knowledge about technology in society.

In contrast to philosophers of technology, the engineering community and engineering educators have traditionally divided knowledge based on disciplines (Ankiewicz, 2013; Hughes, 2004; Mitcham, 1994). For example, electrical engineering education commonly combines scientific knowledge about electrical and magnetic fields (physics) with knowledge about electrical safety standards. The content belongs together not because of some epistemological similarity, but because it is of use in the same branches of industry. In a similar way, production engineering combines knowledge about materials and manufacturing processes, based on both science and professional experience, with knowledge about

production planning and ergonomics. They are grouped together because they are used in industrial production, but are gained, learned and justified in different ways.

In terms of technology education, the parts of the technological domain that are included vary between countries and over time, as mentioned above. For example, cooking and nutrition belong to the domain of school technology in England—food technology as a theme within the subject of design and technology—while in Sweden they instead belong to the subject of home and consumer studies (Department for Education, n.d.; Skolverket, 2020).

Technology education tends to include the relationship between technology and society, for example how technologies such as computers affect our lives, in technological knowledge (e.g. de Vries, 2016; Norström, 2014; Ropohl, 1997). Furthermore, de Vries (2016) argues that technological knowledge is often related to value judgments, and that it demands normative considerations of a kind not seen in science, which has consequences for teaching:

There is normativity in science as well, but mainly with respect to the norms for what we accept as scientific knowledge or not, and not with respect to the objects of the knowledge. One cannot say that an electron is bad or good. As soon as one starts making statements about its suitability to do something, one has already passed the border to technology, because a practical purpose or application is then at stake. This difference between scientific and technological knowledge, no doubt, has its consequences for teaching those different types of knowledge (de Vries, 2016, p. 8).

Framing technology education in terms of an epistemological tripod

By analysing and reflecting on technology education, and by drawing on the various philosophical and theoretical views of technology described above, we propose a heuristic framework for technology education based on technological knowledge traditions. We note that most content within technology education can be related to the knowledge traditions of *craftsmanship*, *engineering* and *humanities and the social sciences*. By knowledge tradition, we mean the combined knowledge and skills that have developed within an (often loosely) organised community, performing similar tasks and exchanging tips, tricks, and information among each other. Knowledge traditions grow organically and are shaped by the needs and interests of the community members. They may in part be ruled by laws and regulations, but their limits tend to be unwritten and constantly negotiated. Knowledge traditions cannot be defined by traditional epistemological categories like methods for justification, but by the communities that use them. Knowledge traditions are not necessarily mutually exclusive, and their limits tend to be fuzzy (cf. Håkanson, 2010).

The proposed heuristic framework consists of an epistemological tripod of technology education, with three mutually supporting legs. Each leg represents one category of technological knowledge, each one based on one of the aforementioned knowledge traditions: (1) technical skills (based on the craftsmanship knowledge tradition), (2) technological scientific knowledge (based on the engineering knowledge tradition) and (3) socio-ethical technical understanding (based on the humanities and social sciences knowledge tradition). The framework is presented in Table 1 and is further explained and unpacked in the following sections.

Unlike most existing frameworks for technological knowledge, the proposed framework is created specifically with technology education in schools in mind. We believe that using this approach has allowed us to formulate a framework which is easy to grasp while also being

Table 1 The three-part heuristic framework for technology education, summarised and visualised

The three legs of the epistemological tripod of technology education			
	Technical skills	Technological scientific knowledge	Socio-ethical technical understanding
Short description of technological knowledge (tradition)	The first technological knowledge mastered by humans. Skill or ability. The main focus is to make things work, not why they work. Knowledge in technology. (Craftmanship tradition)	Knowledge gained using a general scientific approach, but in a technological context. Understanding why things work is of the greatest importance. Knowledge in technology. (Engineering tradition)	Discussing and relating technology to different aspects such as the environment, society and humans. Knowledge about technology and its relationship with the human world. (Humanities and social sciences tradition)
Main justification method	Experience	Methods from the technological and natural sciences	Methods from the humanities and the social sciences
Example from technology education	Knowledge of how to build, cut and glue cardboard models	Knowledge of how materials are structured and their properties	Knowledge of how computers have changed the way we communicate or how society's infrastructure is designed
Example from professional activities	Craftwork of a blacksmith	Mechanical calculations of the strength of a bridge	How a new railway line will affect the everyday life of the local community

compatible with educational traditions. In turn, this should make it useful for the analysis and comparison of syllabi, textbooks, lessons and more. The intention is to provide a heuristic frame of reference for comparisons between, and discussions of, the curriculum components and learning objectives of technology education, rather than a comprehensive philosophical account of technology. By focusing on technological knowledge traditions—craftsmanship, engineering, and humanities and the social sciences—and how they make up the core of the subject, we address technology education from a distinctly different angle compared to initiatives to apply existing frameworks in a technology education context, such as Ankiewicz's (2013, 2015) use of Mitcham's (1994) model in relation to dimensions of technology.

Technical skills

The first knowledge category in the framework is technical skills, which was also the first kind of technological knowledge to be mastered by humans (Dakers, 2019). Knowledge in this category is originally derived from craftsmanship or other types of experience-based knowledge traditions and is justified mainly by experience and trial and error (e.g. Ropohl, 1997; Vincenti, 1990). It tends to be expressed as actions rather than verbally (Molander, 1996). It is the kind of knowledge that is taught in craft and technical education and used by craftsmen and technicians in their professions and trades. Historically, this kind of knowledge has been a major part of technology, and it is what the apprentice learns from the master. The most important thing is not *why* things work, but *that* they work. Common activities include making, sketching, drawing, measuring, merging, repairing and so on. The methods and tools of the craftsperson has changed over time, but the focus on what works (rather than why it works) has dominated throughout history.

Technological scientific knowledge

The second category is technological scientific knowledge. As the name implies, this is technological knowledge gained using a general scientific approach (but not necessarily based on natural science). This knowledge type mainly arises from engineering science and natural science traditions and is often represented using mathematical models (cf. Hansson, 2007, 2013). Furthermore, knowledge is often justified by scientific methods, although standards and practices (Norström, 2014) are also foundations for knowledge in this category. This knowledge is used by engineers and taught in engineering education (e.g. Gross et al., 2018). In this knowledge category, understanding *why* things work is often as important as knowing *that* it works. Common activities include analysing, calculating, describing, measuring, documenting, engineering drawing and so on. Engineering is a predominantly academic knowledge tradition, mainly learnt through formal education. The methods of engineering are to some extent based on experience, but are mainly implemented in scientific experiments, methodical testing or formal standards. Explanation and modelling have prominent places in the engineering tradition.

Socio-ethical technical understanding

The third category is socio-ethical technical understanding, which deals with the relationship between technology and the human world; it is knowledge *about* rather than *within* technology. In other words, it is knowledge viewed from the perspective of a critical

philosophy of technology (e.g. de Vries, 2005, 2016), or what Mitcham (1994, p. 39) refers to as a “humanities philosophy of technology”. Consequently, it deals with actions in the human world. In this sense, the category diverges from the two categories described above. While the latter focus on the creation and use of technological artefacts or systems, socio-ethical technical understanding emphasises for example sociological, ethical, political, and environmental aspects of technology. This kind of knowledge is cultivated, for instance, among ethicists, historians and sociologists of technology. Socio-ethical technical understanding thus includes knowledge about sociological, historical, political and ethical perspectives on how the role of technology in society can be understood and evaluated (cf. Ropohl, 1997). The main focus is to teach students to discuss and relate to, for example, different aspects of technology related to time (the past, the present and the future) and to reciprocal actions between the development of technology and the development of society. Knowledge in this category is justified by research methods, most commonly from social sciences and the humanities. Common activities include describing, comparing over time, analysing, evaluating from ethical and sustainable development points of view, and so on.

Examples of the tripod in technology education

To further explain the three categories of knowledge, a few examples of common subject content in technology education will be used to illustrate the characteristics of the three legs of the tripod. Three examples of subject content—*materials*, *computers* and *design*—will illustrate how technological knowledge appears differently depending on the perspective from which the examples are considered. These three examples of subject content in technology education show that in order to get as complete an understanding as possible, it is necessary to approach the subject content from the perspectives of all three legs of the tripod.

Materials

Materials is a common subject content in technology education, for example in the United States and in Sweden (ITEA, 2007; Skolverket, 2020).

Knowledge of materials as *technical skills* focuses on how the materials are used: What are they used for? How can they be shaped and processed? What material is most appropriate to use in a specific situation? It can also include the learning of actual skills necessary to handle, shape and use the material.

Knowledge of materials as *technological scientific knowledge* focuses on things like their microstructure, and their chemical and physical properties: What are the physical and mechanical properties of this material? How can materials be used in industrial processes? If we use a specific material in a product, how can it be recycled? If we use a specific alloy in a beam, what would its tensile strength be?

Knowledge of materials as *socio-ethical technical understanding* focuses on how the use of materials is related to society: How do plastic materials affect marine wildlife? How did the steel industry affect, and how was it affected by, the development of the Swedish welfare state? How will new materials developed today influence the environment and health in the future?

To sum up, all three legs of the tripod can be used to answer questions about which material would be most appropriate to use in a specific context, but the answers will be based on different traditions of knowledge; the question “Is the beam likely to break?”, for

instance, can be answered by referring to experience (*technical skills*) or by performing stress and strain calculations (*technological scientific knowledge*).

Computers

In many countries, for example England and New Zealand, computers are a common subject content (e.g. Department for Education, n.d.; Ministry of Education, 2018).

From the perspective of *technical skills*, knowledge of computers relates primarily to installation, networks, and computer hardware. It can also be the practical skills concerned with use and configuration of computers and software, learnt from experience and trial and error and used in practical applications.

From the perspective of *technological scientific knowledge*, the design of computer software, knowing that computers use binary numbers which are represented electronically, and knowing that the internet is a global technological system, are all examples of relevant knowledge. Knowledge of programming is also relevant, but in this category knowledge of how an algorithm can be used to solve a problem does not necessarily imply the ability to perform programming.

Knowledge of computers from the perspective of *socio-ethical technical understanding* is knowledge of how computers affect our lives and society, for example, how computers have changed the way we communicate, how infrastructure in society is designed, or ethical aspects of computerisation.

Design

Design is a common content in technology education. In some countries, for example in Ireland, design is salient (Government of Ireland, 2018) and in other countries, like Sweden, design is less dominant (Skolverket, 2020). A student assignment about developing a bench for use in the schoolyard is used as a context to illustrate knowledge of design from the three categories.

Knowledge of design as *technical skills* focuses on how the design problem should be solved. It includes knowledge of the design process and how the steps in the process are performed successfully. It also includes knowledge of how to build a model of the product from cardboard or clay, or how to test its functions.

Knowledge of design as *technological scientific knowledge* could focus on comparing materials for use in the final product, considering their chemical, physical and economic properties such as corrosion, costs and possible manufacturing methods. It could also involve consideration of standard dimensions of seating.

Knowledge of design as *socio-ethical technical understanding* focuses on gaining knowledge of the needs of the target group or how the position of the bench could affect how students move in the schoolyard. It could also concern how material choices affect sustainability, for example by evaluation of FSC certification for sustainable forests (Forest Stewardship Council, n.d.).

The tripod in relation to other classification systems of technological knowledge

As mentioned above, our framework is designed specifically to provide a useful tool for analysing, comparing, discussing, and understanding technology education in schools. Different classification systems have different structures and foci and are based on different

premises. Therefore, it is not always easy to evaluate such systems or to compare them with each other. However, to further explain the tripod and its usefulness, we will discuss it in the context of the examples of content knowledge in technology education above and in relation to a selection of views or models of technological knowledge.

The example of knowledge of materials as *technical skills*—how materials are used and how they can be shaped and processed—suggests a carpenter or a blacksmith, or in a technology education context, a student performing an assignment to explore and try out different materials. This kind of knowledge can be described as knowledge gained by practice, and includes to a large extent what Ropohl (1997) calls *technical know-how*, what Hansson (2013) refers to as *tacit knowledge* and what Vincenti (1990) names *practical considerations*. However, it could also include Ropohl's *functional rules* on what to do in a particular situation to gain a desired result; the kind of knowledge also known as *rules of thumb* (Norström, 2011) and *practical rule knowledge* (Hansson, 2013), if the knowledge used by the carpenter or the student in that particular situation is gained from previous experience.

Moreover, knowledge about what to do in order to achieve a desired result, for example *functional rules* (Ropohl, 1997), *rules of thumb* (Norström, 2011) and *practical rule knowledge* (Hansson, 2013), can also be related to *technological scientific knowledge* if the tradition of the knowledge or the rule is based on knowledge derived from scientific methods. This could, for example, involve using a specific alloy in a beam, based on which alloy has been used before, since the knowledge of the alloy and its properties is gained from scientific knowledge.

Applied natural science (Hansson, 2013) is the kind of knowledge that is used when using (applying) results or knowledge from the natural sciences to solve a technical problem. In our example of materials, this could involve using knowledge about the electronegativity scale (from chemistry) to select a material that resists corrosion, which we would describe as *technological scientific knowledge*.

In the example about design as subject content in technology education, Ropohl's (1997) *structural rules* are relevant as they deal with how to produce knowledge about non-existent objects or systems, represented by sketches and drawings of the bench. Structural rules can be examples of both *technical skills* and *technological scientific knowledge*. A quick sketch by hand is carried out using a *technical skill*, and a model created in CAD including calculations of stress and strain is an example of applying *technological scientific knowledge*.

Hansson's (2007, 2013) category of *technological science* focuses on making things work, and is described as when "technological constructions are investigated with scientific methodology" (2013, p. 17), i.e. using the same procedures that usually are applied in science in order to obtain reliable results in technology or engineering. Examples of this category include wind tunnel testing and other practical direct testing of technological constructions, such as crash testing cars. These experiments are carried out using sound scientific procedures—calibrated measuring instruments, statistical analysis, etc.—just as in the natural sciences. The main difference to the natural sciences concerns the objects of study: technical artefacts rather than natural phenomena. In relation to our example of design, this could involve testing different shapes and designs on the target groups, based on scientific methods, to get a collective picture of which design to choose. This would be an example of *technological scientific knowledge* in our framework.

Vincenti (1990) divides technological knowledge into six categories. The categories are based on skills and knowledge used in historical aeroplane design projects. Some of the categories are comparable to what students are supposed to learn in technology education, while other are too context-specific. Since his theory is based on the design process,

it is most appropriate to apply it to our example of design. His *design instrumentalities* category is procedural knowledge of how to perform the design process, i.e., an example of *technical skills* as described as the knowledge of the process in the example of design above. Vincenti's *practical considerations* are described as being "mostly learned on the job rather than in school or from books" (p. 217) and are an example of knowledge that we would call *technical skills*. In the example above, this could be the knowledge of building models from cardboard or clay, which is learned by doing the actual building. One of Vincenti's categories—*theoretical tools*—could be considered part of our *technological scientific knowledge* leg since it includes "intellectual concepts for thinking about design as well as mathematical methods and theories for making design calculations" (p. 213). The rest of Vincenti's categories are not directly comparable with or transferable to our framework since Vincenti's framework was created for technological knowledge in the context of designing aeroplanes and ours is based on knowledge in technology education.

Besides Vincenti's classification system, there are also other systems for categorising technological knowledge which, due to fundamental differences in approaches, are difficult to compare with our tripod. For example, Mitcham (1994) presents a conceptual framework of technology. His four dimensions represent four fields of philosophy: *objects* (which mainly has ontological considerations), *knowledge* (epistemological considerations), *activities* (methodological considerations) and *volition* (dealing with aims and purpose). Since Mitcham's framework theorises and categorises knowledge in a different way than our framework, his categories are not directly transferable to our view of knowledge. Nevertheless, knowledge *about* technology as volition could be seen as an example of *socio-ethical technical understanding* in our framework. In the above example of computers and how they affect the way we communicate, an understanding of the driving forces for development of those technologies—how they express and are a result of our will to communicate—is an example of socio-ethical technical understanding or, in Mitcham's terms, knowledge about technology as volition. Knowledge about technology as objects can include examples of knowledge in all our three categories, depending on which perspectives we choose in the teaching of technological objects.

Ryle (1949) focuses on knowledge in general, and divides knowledge into *knowing that* and *knowing how*. Nevertheless, his take on knowledge has been referred to when describing technological knowledge by philosophers of technology (e.g. de Vries, 2016; Norström, 2015). Somewhat simplified, technical skills is based on what Ryle calls *knowing how*. Technological scientific knowledge consists mainly of *knowing that* (but also to some extent of *knowing how*). Socio-ethical technical understanding consists almost exclusively of *knowing that*. Ryle's (1949) division of knowledge has been criticized, mainly for his system's inability to describe interchange between different types of knowledge (whether knowing how can lead to knowing that and vice versa), and that he is mistaken about the fundamental differences between the types (e.g. Norström, 2015; Bzdak, 2008; Stanley & Williamson, 2001). This does not affect the relation between *knowing how*, *knowing that*, and the legs of the tripod as the latter are based on *traditions* of technological knowledge rather than conventional epistemological characteristics. McCormick (1997) introduces categories similar to Ryle's in his classification system: *procedural knowledge* and *conceptual knowledge*. These categories can be related to the tripod in a similar way to Ryle's, and some of the criticism stands. The distinction between procedural and conceptual knowledge is not watertight.

Our third leg, *socio-ethical technical understanding*, is less commonly represented in the philosophical frameworks that we have presented so far. One exception is Ropohl's (1997) category *socio-technological understanding*, which he presents as follows:

“Socio-technological understanding is a systemic knowledge about the interrelationship between technical objects, the natural environment and social practice” (p. 70). More examples of this kind of technological knowledge, i.e. knowledge *about* technology, are found among the philosophies that Mitcham (1994) terms *humanities philosophy of technology*. This view of technology seeks the meaning of technology in relation to areas such as ethics and politics (e.g. Winner, 1986).

The discussion above reveals how the tripod is related to a number of previous epistemological and other frameworks of technology to which it owes some of its philosophical basis. The fundamental difference is that our framework takes the *traditions of technological knowledge* underlying technology education as its starting point, symbolised by the three legs of our metaphorical tripod. We thus use concepts that are more manageable for a school context. In some cases, they may be less precise. The categories are however more adapted to the way teachers and educators relate to technology than the existing frameworks.

The tripod in relation to technological literacy

The concept of technological literacy refers to a general ability to see the big features of technological phenomena—to understand and use it in a productive way—rather than particular skills, methods, or facts (e.g. Jenkins, 1997). It is a relatively vague concept and there is no consensus concerning its definition. Still, there are many examples in the literature where technological literacy is discussed in a technology education context. Although the tripod is not primarily a framework for technological literacy, it can be used to gain further understanding of—and specify components of—technological literacy. The framework can be used as a tool for teachers to plan their teaching in order to help students obtain technological literacy. As a first step towards improved technological literacy, technology (e.g. important technologies, artefacts and systems) could be studied using all three legs of the tripod. When gaining *technical skills*, *technological scientific knowledge* and *socio-ethical technical understanding* of relevant technology areas—such as water and sewerage systems, or other examples of the basic infrastructure needed for society to operate—students will develop their knowledge and understanding to gain the holistic view of technology that is necessary for technological literacy.

Williams (2017) argues that the traditional competency-based technology education was too narrow to be considered suitable to support the development of a technological literacy, but today technology education is broader. According to Williams, technological literacy is the most significant goal of technology education, and generally consists of three dimensions: (1) an ability/use dimension, (2) a knowledge and understanding dimension, and (3) a dimension concerning awareness or appreciation of the relationship between technology, society and the environment (cf. Dakers, 2006). There are obvious similarities between Williams’ dimensions and the legs of the tripod, but they are not identical. We argue that to obtain technological literacy, all three kinds of knowledge in our framework are needed.

In some countries, such as the United States, technological literacy is explicitly included in technology education. The *Standards for technological literacy: Content for the study of technology* state that: “With the growing importance of technology to our society, it is vital that students receive an education that emphasizes technological literacy” (ITEA, 2007, p. vii). Furthermore, technological literacy is defined in the standards as “the ability to use, manage, assess, and understand technology” (ITEA, 2007, pp. 7, 9). In this sense, broad knowledge about technologies is a necessary precondition for becoming technologically

literate. In other countries, such as Sweden, technological literacy is hinted at in the curricula, even though the expression is not used. The purpose of the technology curriculum is that students should develop their “technical awareness and an ability to relate technical solutions and their own use of technology to issues related to sustainable development.” (Skolverket, 2020, p. 1). In New Zealand, students are expected to “develop broad technological knowledge, practices and dispositions that will equip them to participate in society as informed citizens and provide a platform for technology-related careers” (Ministry of Education, 2018, p.1).

The framework in relation to technology curricula

One of the main purposes of the framework is to provide a tool for the analysis and comparison of technology curricula. Even though technology education varies in different countries, its content can mainly be reduced to the three categories in our framework. The usefulness of the framework is demonstrated here by applying it to the English and Swedish technology curricula.

The school subjects of *technology* in Sweden and *design and technology* in England were selected for this analysis because they have quite different characters and should therefore be interesting to compare using the framework. Design and technology is described as follows:

Design and technology is an inspiring, rigorous and practical subject. Using creativity and imagination, pupils design and make products that solve real and relevant problems within a variety of contexts, considering their own and others’ needs, wants and values (Department for Education, 2013).

The Swedish technology curriculum is undergoing a revision at the time of writing. The revised version (Skolverket, 2020) will be implemented in 2021. The aim of the Swedish technology subject is described as follows:

The teaching of the subject of technology should aim for students to develop an interest in and knowledge of the technology that surrounds us. Students should be given opportunities to develop an understanding that technology is significant to and affects humanity, society, and the environment. In this way, students can develop a technical awareness and an ability to relate technical solutions and their own use of technology to issues related to sustainable development (Skolverket, 2020, p. 1).

As the quotations show, the subjects have different foci. In the English curriculum, students’ design and make activities are the core, while in the Swedish one the main emphasis is on students’ technological literacy.

For this comparison, similar parts of the texts of both curricula were studied. Each curriculum was analysed separately—see Tables 2 and 3. In the English curriculum, the “Subject content” section for key stage 3 (i.e. for students aged 11–14) was analysed, specifically the main four headings. In the Swedish curriculum, the section describing core content (*centralt innehåll* in Swedish) was analysed. The subject core content section for grades 7–9 (i.e. for students aged 13–16) is divided into three headings containing examples of what to teach to achieve the goals. The analysed school years are the last part of compulsory technology education in both countries. For each analysis, the respective curriculum document was scanned for formulations specifying what students are intended to

Table 2 English curriculum

Description in the curriculum	Main identified legs from the tripod
Subject content, key stage 3 When designing and making,	
Design	Socio-ethical technical understanding
Use research and exploration, such as the study of different cultures, to identify and understand user needs	
Identify and solve their own design problems and understand how to reformulate problems given to them	Technical skills
Develop specifications to inform the design of innovative, functional, appealing products that respond to needs in a variety of situations	Technical skills and technological scientific knowledge, depending on the project
Use a variety of approaches [for example, biomimicry and user-centred design], to generate creative ideas and avoid stereotypical responses	Technical skills
Develop and communicate design ideas using annotated sketches, detailed plans, 3-D and mathematical modelling, oral and digital presentations and computer-based tools	Technical skills (technological scientific knowledge)
Make	Technical skills
Select from and use specialist tools, techniques, processes, equipment and machinery precisely, including computer-aided manufacture	
Select from and use a wider, more complex range of materials, components and ingredients, taking into account their properties	Technical skills (technological scientific knowledge)
Analyse the work of past and present professionals and others to develop and broaden their understanding	Technical skills, technological scientific knowledge and socio-ethical technical understanding, depending on the kind of work analysed
Investigate new and emerging technologies	Technical skills, technological scientific knowledge and socio-ethical technical understanding, depending on the kind of technologies and the kind of investigation
Test, evaluate and refine their ideas and products against a specification, taking into account the views of intended users and other interested groups	Technical skills
Understand developments in design and technology, its impact on individuals, society and the environment, and the responsibilities of designers, engineers and technologists	Socio-ethical technical understanding

Table 2 (continued)

Description in the curriculum	Main identified legs from the tripod
Technological knowledge	Technological scientific knowledge
Understand and use the properties of materials and the performance of structural elements to achieve functioning solutions	Technological scientific knowledge
Understand how more advanced mechanical systems used in their products enable changes in movement and force	Technological scientific knowledge
Understand how more advanced electrical and electronic systems can be powered and used in their products [for example, circuits with heat, light, sound and movement as inputs and outputs]	Technological scientific knowledge
Apply computing and use electronics to embed intelligence in products that respond to inputs [for example, sensors], and control outputs [for example, actuators], using programmable components [for example, microcontrollers]	Technical skills (technological scientific knowledge)

Table 3 Swedish curriculum

Description in the curriculum	Main identified legs from the tripod
Subject content in school years 7–9 Technology, human, society and environment	Socio-ethical technical understanding (technological scientific knowledge)
The internet and other global technological systems and their benefits, risks and limitations	Socio-ethical technical understanding
Opportunities, risks and security in technology use in society, including when storing data	Socio-ethical technical understanding
Consequences of technology choices based on ecological, economic and social aspects of sustainable development	Technological scientific knowledge
How technology has enabled scientific discoveries and how science has enabled technological innovations	Socio-ethical technical understanding
How conceptions of technology affect individuals' use of technical solutions and career choices	Technological scientific knowledge
Technical solutions	Technological scientific knowledge
How components and subsystems are named and interact together in technical systems, such as information and communication technology and transport systems	Technological scientific knowledge
Technical solutions for control and regulation by means of electronics and various types of sensors. How technical solutions that utilise electronics can be programmed	Technological scientific knowledge
Technical solutions for strong and sturdy constructions and the importance of the properties of materials, such as tensile and compressive strength, hardness and elasticity	Technological scientific knowledge (technical skills)
Processing of raw material for finished products and handling of waste in some industrial process, for example, in the manufacture of food and packaging	

Table 3 (continued)

Description in the curriculum	Main identified legs from the tripod
Working methods for the development of technical solutions	Technical skills and/or Technological scientific knowledge, depending on the project
The different phases of technological development: identification of needs, investigation, proposals for solutions, construction and testing. How the phases of the work process interact in the students' own work and in technology development work in society, for example in architecture and public transport	
How digital tools can be used in technology development work, for example for producing drawings and simulations	Technical skills
Students' own designs, in which control or regulation is applied by means of programming	Technical skills and/or Technological scientific knowledge, depending on the project
Documentation of technical solutions: sketches, drawings, physical and digital models, as well as reports describing technology development and design work	Technical skills (technological scientific knowledge)

learn. The identified statements were then analysed with respect to the legs of the tripod. Most formulations could be tentatively associated with a single main category, but in some cases several categories were possible.

Technology in the English curriculum

In England, the current curriculum was introduced in 2013 and the subject is called design and technology (Department for Education, 2013). Design and technology is a compulsory subject in key stages 1–3 (years 1–9) (Department for Education, n.d.).

In Table 2, the subject content of key stage 3 is analysed, and each type of content is categorised as one or more of the three legs of the epistemological tripod of technology education. The results show that the English curriculum is dominated by *technical skills* and *technological scientific knowledge* although all three legs are represented.

Technology in the Swedish curriculum

In Sweden, the subject is called technology and is a mandatory subject in compulsory school. The curriculum that was analysed will be used in Swedish schools from 2021 (Skolverket, 2020), and is slightly revised compared to the one in use at the moment of writing (Skolverket, 2017).

Table 3 categorises extracts from the curriculum for grades 7–9 that specify relevant subject content in terms of the three legs of the epistemological tripod of technology education. The results suggest that all three legs are represented to approximately the same extent in the Swedish curriculum.

The application of the framework to two examples of technology education curricula shows that the framework functions as an analytical tool. Technical skills and Technological scientific knowledge are the dominating aspects of technological knowledge in the English syllabus for design and technology, whereas the Swedish curriculum contains the three categories to approximately equal degrees. The framework can thus account for and describe a diversity of subject content and different characteristics of curricula. All in all, therefore, the framework is promising and appears to be useful as an analytical tool for technology education.

Discussion

Technological knowledge classification systems or frameworks have different built-in premises and presumptions and are designed for specific contexts. This also means that the knowledge categories of these frameworks are created and sorted in different ways. For example, some well-known frameworks are based on the design process or on the nature of artefacts (e.g. Vincenti, 1990, and de Vries, 2003, respectively). Consequently, it is usually challenging to compare ways of categorising with each other, although they all have pros and cons. Our heuristic framework, which we have described using the metaphor of a tripod of technology education, has been developed for a school context based on knowledge traditions (such as craft/sloyd, engineering/science, ethics.). The three categories are not mutually exclusive, since there are examples of knowledge that are important for more than one category or tradition of knowledge. In addition, one subject component in technology education can be viewed and taught from the perspectives of all three categories. Hence, it

differs from most previous technological knowledge frameworks, as illustrated by the overlapping categories from other categorisation systems.

Nevertheless, our framework is only a model, and—as models generally do—it helps us to understand and describe a complex reality by a degree of simplification. Models are compromises, in this as in many other cases between ease of use and level of detail. The tripod with its three categories of knowledge is graspable. While a greater number of categories could provide the opportunity for more detailed descriptions and analyses, it would also be more difficult to use. The framework does not imply that the categories of knowledge can always be disentangled and separated in educational practice. In technology education classrooms, a teacher can have a teaching focus on one leg at a time but can also focus on two or all three legs at the same time. For example, to be able to gain a socio-ethical technical understanding, some technological scientific knowledge is also needed, because this knowledge is needed in order to be able to evaluate, discuss and reason about different perspectives and alternatives.

The heuristic framework is thus a conceptual model (Pirtle, 2009) for teachers, teacher educators, and researchers to be able to describe and compare curriculum components in technology education, and possibly also support practitioners in finding good solutions for technology teaching. The framework may indicate if there is a breadth of technology knowledge that could support technological literacy, or if the focus is on just one or two of the three legs. Furthermore, in addition to analysing technology curricula as demonstrated above, the framework can also be used to analyse textbooks and other technology education-related teaching materials and exercises. The framework can be a way to increase understanding of technology education among teachers and researchers from different countries, as well as among people from different technology education backgrounds, both nationally and internationally.

Yet, the framework has its limitations. Firstly, the framework only includes technological knowledge, *what* to teach, not other aspects of technology education like the purpose of the teaching, *why* to teach technology, or the methodology of teaching, *how* to teach technology. Furthermore, there are skills and traits that are sometimes related to technology education but could not really be categorised as technological knowledge per se, such as creativity, flexibility, communication, collaboration, etc. (e.g. Schooner et al., 2017); these are not included in this framework. Thus, the framework is useful for example when discussing subject content or technological literacy with pre-service or in-service teachers.

In conclusion, although there are a number of existing epistemological and other frameworks of technology, our new heuristic framework—the tripod—is designed within and for a technology education context. The knowledge categories are more adapted to the way teachers, teacher educators, and educational researchers—as well as technological professionals—naturally relate to technology and technology education than the existing frameworks. The fundamental difference between them and the tripod is that our framework takes as its starting point the three main *traditions of technological knowledge* underlying technology education, symbolised by the three legs of our metaphorical tripod. We have shown that the framework is useful and valid for analysing technology curricula, and that it is a potentially powerful tool for concretising the components of technological literacy.

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