

Taxonomies of technological knowledge in higher education: A mapping of students' perceptions

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This paper presents the findings from a qualitative study exploring students' perceptions of what constitutes technological knowledge. Technological knowledge dimensions from previous literature do not seem to be student-led, but rather suggested by the authors. It is therefore important to incorporate student views in order to create a more evidence-based taxonomy. Previous taxonomies of technological knowledge are also heavily linked to engineering-related disciplines, however definitions for use across the field of education and learning technologies would be helpful. In this study, a sample of student volunteers were interviewed about their understanding of technology enhanced learning and technological knowledge. The students were from a range of disciplines, not just engineering and science, so that technology knowledge for the general student population would be represented. An inductive thematic analysis was then carried out on the interview transcripts. Three knowledge types were derived from the thematic analysis: practical knowledge; structural knowledge; and computer science knowledge. These three empirically-derived technological dimensions were then mapped onto existing taxonomical structures from the literature. Finally, this paper discusses the implications of the student-generated dimensions for educators.

Implications for practice or policy:

- Educators may need to consider how student-generated types of technological knowledge map onto existing technological knowledge structures and Bloom's taxonomy.
- Educators can use the types of technology knowledge to target their teaching to their learners' required knowledge level.

Keywords: technological knowledge, mapping, student perceptions, qualitative, thematic analysis

Introduction

Technological knowledge and digital fluency are increasingly a part of higher education, as well as earlier phases of education and the workplace. Many UK universities present sets of graduate attributes, which are the competencies that students are expected to develop over the course of their degrees (Wong et al., 2021). Many institutions suggest students develop *digital fluency* or *digital capability* (The University of Sheffield, 2021), and Wong et al. (2021) found that nearly a third of UK universities suggest a graduate attribute of students being "agile users of digital devices and online platforms" (p. 1). Furthermore, most university learning and teaching strategies include some comment on the use of technology, with many incorporating this graduate attribute as well. For example, London School of Economics and Political Science suggests it will "enable students to produce diverse outputs, developing digital fluency and entrepreneurial confidence" (London School of Economics and Political Science, 2020, "How we will do this", point 3), and Edinburgh University says that "in reshaping our teaching for the future, we expect to expand interdisciplinary and multidisciplinary, postgraduate and digital education" (The University of Edinburgh, 2020, "Teaching and Learning", paragraph 4). In addition to this increasing focus on digital literacy upskilling for students across the course of their degrees, there may be sudden circumstances where technology skills are of utmost importance. For example, during the COVID-19 pandemic, educators and students were expected to rapidly pivot to online learning. This required the students to already hold, or rapidly gain, a high degree of technology competency. They were expected to access online learning and assessment from home, and use new software for applications such as videoconferencing and uploading handwritten exams. These actions are underpinned by the students' tacit technological knowledge that is rarely conscious (Lambe, 2014). It is therefore important for educators to understand this underpinning knowledge and the dimensions that constitute it, in order to explore its relation to practical utility. Tools can be created that scaffold knowledge (Lambe, 2014), and this is also true of technological knowledge when educators are designing learning activities and pedagogies.

This paper explores higher education students' perceptions of the dimensions of technological knowledge in order to bring tacit, unconscious knowledge to the fore. The study then explores how the student-generated dimensions of technology knowledge map on to existing taxonomies in the literature, and finally discusses why this is a useful tool.

Knowledge taxonomies

Taxonomies of knowledge are semantic schemes of classification that can help educators and students to organise and manage their knowledge through retrieval, interpretation, and subsequent decision making (Lambe, 2014). Classification schemes allow the creation of knowledge maps, which demonstrate knowledge domain structures and the relationships between them, as well as allowing the user to locate current knowledge and position new knowledge. This is particularly important as we move forward in an increasing-technological world where the knowledge is both about the technologies used, as well as aided by technology (Kaya, 2015). A taxonomy of any kind is a lens through which the world can be viewed and interpreted, and provides a structure in which to have conversations about these views and interpretations (Lambe, 2014). The ability to have conversations within the structure provided by the taxonomy reduces what Lambe (2014) calls the *Babel instinct* where, even within the same field or organisation, the language used is highly localised, meaning that the same concepts may be given different names by different groups. The Babel instinct may mean that conversations or other teaching and research activity may miss great swathes of similar activity due simply to terminology differences. Taxonomies can help to reintegrate these groups and activities (Lambe, 2014), and perhaps apply understanding of the different terminologies to educators and researchers across wider transdisciplinary activities, spanning the humanities, social science, and the sciences (Alvargonzález, 2011).

Knowledge taxonomies in particular can be used to design and assess educational materials, determining which cognitive levels are being aimed at and how successfully the materials and students are meeting these aims. They can also be used to determine how well aligned assessments are to course learning objectives (Coleman, 2017). In the past, Bloom's revised taxonomy in particular has been widely used for this purpose (Anderson et al., 2001; Kiesler, 2020). The alignment of materials, assessments, and knowledge taxonomies therefore means it is important to consider the structure of the taxonomy before, during, and after learning design.

Technological knowledge

First, it is important to point out the difference between technological knowledge and digital fluency. Digital fluency is a concept defined by Wang et al. (2012) as a practice-oriented and developmental process where users develop their own ability to use technology according to their own needs and interests. In contrast with digital fluency, technological knowledge is about the different types of epistemological knowledge possessed by students (Houkes, 2009). It is the structure of knowledge that underlies the practical application of knowledge. Technological knowledge and digital fluency can be considered in a symbiotic relationship with one another, but they are not the same entity.

Technological knowledge is defined in various ways by different people. Even technology teachers interpret and assess technology knowledge differently from each other (Norström, 2014). There is also a difference drawn by some authors between knowledge about the history of technology (e.g., the effect on society and disciplines of technological developments) and technological knowledge. Technological knowledge is more about knowledge in technology, and the skills and facts involved (Norström, 2014). It has been found to be distinct from the knowledge of science in its objectives and methodologies, and therefore requires its own definitions (Houkes, 2009; Ropohl, 1997). These have not yet been agreed upon within the literature and likely vary depending on the aims of the educator.

Knowledge is often viewed as a crystallised form of facts, or a "justified true belief" (de Vries, 2003, p. 117). Since this project was carried out through the lens of a constructivist worldview, the assertion that any belief is ontologically true is not made. However, where facts can be defined as the current scientific consensus, combined with names and other crystallised knowledge, this is known as *declarative knowledge* (Hong et al., 2018, p. 75). There are several types and taxonomies of knowledge that constitute a person's knowledge base, and declarative is but one type. There are other types of knowledge, and multiple types of knowledge are also appropriate for technology knowledge (de Jong & Ferguson-Hessler, 1996; de Vries,

2003). Procedural or heuristic knowledge is a second common type, which is described as being able to carry out a skill or group declarative knowledge into useful domain-specific units (de Jong & Ferguson-Hessler, 1996; Hong et al., 2018).

Bloom's revised taxonomy (Anderson et al., 2001) presents another framework of types of knowledge. The revised taxonomy updates the original taxonomy of educational cognitive objectives with a refocus towards a dynamic verb-noun process. Anderson et al (2001) also incorporated a second dimension into the framework, resulting in a knowledge dimension and a cognitive process dimension. Table 1 presents the revised taxonomy in a 2-dimensional matrix. The cognitive process dimension demonstrates the verb – what the objective suggests the student should be doing. The knowledge dimension demonstrates the noun – what piece of knowledge the objective pertains to. There are four knowledge dimensions: factual knowledge is about the basics of terminology and elements; conceptual knowledge is about how the basic elements fit and function together; procedural knowledge is about skills and methods of how to do something; and metacognitive knowledge is about self-knowledge and awareness of cognition generally and personally (Anderson et al., 2001; Barak, 2013). The matrix was designed so that every educational objective written using the taxonomy could be placed within a single cell. This is particularly useful for helping educators recognise the relationship between knowledge and the cognitive processes (Anderson et al., 2001). The revised taxonomy has been used successfully for analysis of technological knowledge dimensions (e.g., Lin et al., 2013).

Table 1
Bloom's revised taxonomy matrix (Anderson et al., 2001)

Knowledge dimension	Cognitive process dimension					
	Remember	Understand	Apply	Analyse	Evaluate	Create
Factual knowledge						
Conceptual knowledge						
Procedural knowledge						
Metacognitive knowledge						

van Merriënboer et al. (2002) suggested a model that explicitly focused on skills and procedures for tasks rather than knowledge type. Some of these could be deemed as types of knowledge. The four categories as suggested by van Merriënboer et al. (2002) were:

1. Compilation – organising specific knowledge into rules,
2. Restricted encoding – incorporation of procedural knowledge into existing rules,
3. Elaboration – incorporating new knowledge into existing knowledge networks through recognition of non-arbitrary relationships, and
4. Induction – active creation of mental models and cognitive strategies by abstraction.

In addition to these general knowledge types by Anderson et al. (2001) and van Merriënboer et al. (2002), there have been several suggestions for types of technological knowledge. Vincenti (1990) suggested six types of technological knowledge for engineering design. These were subsequently modified for other technology applications, as well as more generally, to three types by de Vries (2003; 2005): (1) physical nature knowledge, which is knowledge of the material properties of technologies; (2) functional nature knowledge, which is knowledge on what technologies can be used for; and (3) action knowledge, which is the action or procedure that one follows to achieve a specific result.

Inde (1997) had suggested several dimensions of technological knowledge, which included: knowledge about technologies, which is how a technology is made and functions, most often possessed by engineers; theoretical knowledge, which is about the underlying principles from physics and chemistry that enable a technology to work; and knowledge through technologies, which is non-technological knowledge that requires technology in order to know, for example, knowledge of the stars (the non-technological knowledge) requires the use of a telescope (the technology). Ropohl (1997), also from the discipline of engineering, suggested five types of technological knowledge:

- 1) Technological laws – organising theoretical knowledge into practical generalisations
- 2) Functional rules – the procedure that one follows to achieve a certain result
- 3) Structural rules – how technology is made and functions, including repairing
- 4) Technical know-how – implicit experience-based skills, usually motor skills
- 5) Socio-technical understanding – knowledge about how the relationship between technology, the environment, and society

These types of technological knowledge seem to have mainly arisen from the field of engineering, although they are not engineering-specific (and those that were, were excluded from this review). The types and taxonomies reviewed can be extrapolated to apply to all fields in which technology is used, including education where learning technologies abound. This has already been shown by Hansson (2014), who suggests four mutually exclusive types of technological knowledge, explicitly to be used in the field of technology education since they focus on the *how* of knowledge. It is clear that these map onto the engineering-based taxonomies, which is shown more explicitly in the next section. Hansson's (2014) types of technological knowledge are: (1) tacit knowledge, which is implicit experience-based knowledge; (2) practical rule knowledge, which is the procedure to follow to achieve a certain result; (3) technological science, which is knowledge derived from the study of technological solutions; and (4) applied science, which is when theoretical knowledge is used to explain or fix a technological solution.

There is also additional depth. For example for tacit knowledge (Hansson, 2014), Dinur (2011) suggests nine individual types of tacit knowledge, including: skill (gained through hands-on practice and experience); cause-effect (non-linear cause-effect problem solving, requires intuition); cognitive (complex attitudes and thoughts); composite (large volumes of knowledge, requiring internalisation to approach); cultural (collective, cultural, largely-automatic knowledge); unlearning (learning new methods, necessitating unlearning of previous ones); taboo (uncomfortable, *socially-loaded* knowledge); human (the use of relationships in the use of the knowledge); and emotional (challenging, often faces emotional issues). Other types of knowledge exist on slightly different axes, for example, whether knowledge is understood on an individual basis or whether it is socially constructed (Schmitt, 1994), or the difference between knowledge breadth and knowledge depth (Xu, 2015).

Mapping types of knowledge

Houkes (2009) considered how different knowledge taxonomies link together, particularly those of Vincenti (1990), Faulkner (1994), Ropohl (1997), and de Vries (2003). Houke's (2009) focus, however, was on an emancipation of the field of technology epistemology from science, and while intersecting with the purposes of this study, is somewhat tangential. This paper, therefore, builds on parts of Houke's initial attempt at mapping, but excludes Vincenti and Faulkner due to their focus on practical specifics of the engineering discipline rather than the underlying epistemological knowledge addressed by the other authors.

Houke's (2009) literature review was updated, with focus on taxonomies of knowledge, types of knowledge, and technological knowledge. Only sources that contributed to technological knowledge as a potentially interdisciplinary concept were included, and sources that dealt with specific types of technology or overly subject-specific knowledge were excluded. The original papers from Houke's (2009) mapping were also included, with the exception of the Vincenti and Faulkner paper, as discussed above. The types of tacit knowledge found by Dinur (2011) were not included as they are too fine-grained for the purposes of this study.

The types of knowledge and technological knowledge were then extracted from each paper, along with their definitions. Including definitions was a vital part of the process as each paper often gave different names for the same type of knowledge (synonymy), or slightly differing definitions with very similar names (polysemy) (Ménard, 2012). The knowledge types and their definitions were then read closely and assessed for similarity and overlap. Many of the types of knowledge appeared to be subcategories of other knowledge types, for example de Vries' (2003) physical nature knowledge, functional nature knowledge and action knowledge that all fit under Ihde's (1997) definition of knowledge about technology. Others contained some of the aspects of a particular type of knowledge but also included additional aspects that meant the mapping was not perfect, for example Ropohl's (1997) technological laws covered Ihde's (1997) theoretical

knowledge, but also contained additional elements. Some knowledge types overlapped with two different categories from another study, for example Ropohl’s (1997) technological laws encompassed Hansson’s (2014) technological science and applied science. Following this close reading of definitions, the knowledge types were arranged visually in a table according to synonymy, similarity, and overlap, with the most related concepts positioned side by side. Table 2 shows a parsimonious visual representation of how each of the types of knowledge identified map onto each other.

Table 2
Mapping types of technological knowledge

Hong et al., 2018	Anderson et al., 2001	van Merriënboer et al., 2002	Ihde, 1997	de Vries, 2003	Ropohl, 1997	Hansson, 2014
Declarative	Factual knowledge		Knowledge about technology	Physical nature knowledge		
				Functional nature knowledge		
Procedural	Procedural knowledge	Compilation		Action knowledge	Functional rules	Practical rule knowledge
		Restricted encoding			Technical know-how	Tacit knowledge
	Conceptual knowledge				Structural rules	
		Elaboration	Theoretical knowledge		Technological laws	Technological science
	Induction				Applied science	
	Metacognitive knowledge					
			Knowledge through technology			
					Socio-technical understanding	

The mapping in this paper includes several types and taxonomies of knowledge, and most of them share common definitions and relationships, even if the naming is different, as per Lambe’s (2014) Babel instinct. The mapping therefore includes both the general knowledge types and the technological knowledge types, as they are clearly linked. Each column is one system of knowledge dimensions, and reading the table left to right allows us to see where there is overlap between various authors’ dimensions. The amount of overlap in the table itself isn’t important, as it is simply a function of the size of the other cells in the mapping.

Most of the types of technological knowledge have analogues, or at least overlap, in other knowledge systems, with two exceptions. It could be argued that Ihde’s (1997) knowledge through technology is not a true type of technological knowledge, or that it could fall under functional nature knowledge (de Vries, 2003), since it is about what technology can be used for. However, the focus presented by Ihde is on the knowledge itself, so it has been classed as its own knowledge type, mapped as not overlapping with any other type of knowledge. The second exception is Ropohl’s (1997) socio-technical understanding, which is knowledge about the relationship between technology, the environment, and society. This type of knowledge is interesting as some of the other types of knowledge touch on it tangentially; for example, metacognitive knowledge could be considered in a societal context as suggested by Schmitt (1994), or

functional nature knowledge can be considered in terms of how societies use technologies. However, socio-technical knowledge is a broader and more meta type of knowledge and was therefore mapped as a separate entity, again not overlapping with any other type of knowledge.

Purpose of the study

In addition to the mapping of types of technological knowledge from the literature in an attempt to bring together fragmented taxonomies, this paper presents the findings from a qualitative study exploring students' perceptions of what constitutes technological knowledge. The technological knowledge dimensions from the literature do not seem to be student-led, but rather suggested by the authors (e.g. de Vries, 2003; Ihde, 1997; Ropohl, 1997). This means that we lack an understanding of how students view technological knowledge, and therefore we also lack an understanding of how to teach them. It is recognised as important that knowledge taxonomies must be created within the world in which they will be used, not in the abstract or by a consultant (Lambe, 2014). It is therefore important to incorporate student views into this model to reduce abstract thinking and to ground the taxonomy within student experience where it will be most useful. Previous models of technological knowledge are also heavily linked to engineering-related disciplines, whereas definitions for use across the field of education and learning technologies would be helpful. This paper therefore explored student-generated types of technological knowledge by asking students about it in the context of learning technologies and technology-enhanced education. It also explored how the student-generated knowledge types map onto existing taxonomies in order to identify similarities and gaps. The following research question was asked:

- What types of technological knowledge were identified by the participants and how do the identified types of technological knowledge map on to the types of knowledge in the literature?

Methods

Participants

This study was done in a Russell Group university in England. Purposeful criterion sampling and typical-case sampling was done by inviting student volunteers from a previous study examining attitudes to technology (Staddon, 2020) for follow-up interviews (Palinkas et al., 2013). A prize draw for an Amazon voucher was offered for interviewees. Fifty students initially volunteered, and all were invited to attend an interview. A total of 11 responded and were interviewed. Table 3 shows the demographic profiles of the interview participants.

Table 3
Interview participant profiles

Pseudonym	Age group	Discipline	Mode of study
Bill	18-21	Arts and humanities	Full time
Daniel	18-21	Engineering	Full time
Emma	18-21	Arts and humanities	Full time
Harris	22-25	Social sciences	Full time
Chun	22-25	Social sciences	Full time
Sophia	26-30	Social sciences	Full time
Julie	41-50	Arts and humanities	Full time
Anne	41-50	Social sciences	Full time
Aylen	41-50	Engineering	Part time
Gwen	41-50	Social sciences	Full time
Felix	61-70	Arts and humanities	Full time

Interview protocol

The volunteer participants took part in a semi-structured interview. The interview protocol (Appendix A) guided the interview, and aimed to explore the same broad topics with each participant, while allowing the conversation to be flexible so that both parties had time for clarifications, and to expand upon participants'

answers (Coiro et al., 2014; Knox & Burkard, 2009). The interview data used for this project was one section of a longer interview that explored use of technology more broadly. All topics were covered in a single interview with each participant. The section of the interview for this study asked what participants understood by the terms *technology enhanced learning* and *technology knowledge*. Some comments and definitions were also drawn from other parts of the interview where participants were asked about their knowledge compared to other people.

The interview protocol and arrangements were piloted with a small number of students from the target population ($n = 3$). Pilot participants were asked whether the questions were clear and easily understood. The researcher also used their own knowledge of the interview to assess the success of the protocol. As a result of the pilot, some changes were made to the interview protocol, including question rewording, reordering, and the addition of explicit probing questions.

Data collection

Interviews were held individually in private meeting rooms within the university. At the start of each interview, the purpose of the study was explained, and the participant was asked to read the information sheet, and sign a consent form. The interviews ranged from 22 to 56 minutes in duration. A digital dictaphone was used to continuously audio record the entire interview.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (University Research Ethics Committee) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The project was reviewed via the University of Sheffield Ethics Review Procedure, as administered by the School of Education. Upon a change of institution to Durham University, the ethics approval was further approved by the School of Education Ethics Sub Committee.

Data analysis

An inductive thematic analysis was used to analyse the data in order to identify and interpret themes and patterns without an existing coding framework (Braun & Clarke, 2006). Combined with a semantic level of analysis, this enabled a flexible approach to the analysis while maintaining richness and complexity (Clarke & Braun, 2017; Maguire & Delahunt, 2017). Thematic analysis consists of six steps (Braun & Clarke, 2006):

1. Familiarisation
2. Coding
3. Identification of themes
4. Reviewing themes
5. Defining themes
6. Reporting

Data familiarisation (step one) occurred at the interview step, and during the following transcription. Transcripts were anonymised using participant pseudonyms before beginning step two, data coding. The coding was done in NVivo using an iterative process – where further codes arose after the initial round of coding, and the transcripts were reviewed again for those particular new codes. Operational code saturation, where no further codes emerge (Saunders et al., 2018), was found after nine interviews, with 95% of the codes being generated within the first four interviews. The codes were reviewed and any that were redundant or had the same meaning were merged (Nowell et al., 2017). The codes were grouped into 10 themes (step three) and reviewed (step four). Reviewing resulted in some of the themes being classed as subthemes, resulting in 5 main themes. These were then named (step five) with a summary word indicating the contents. The codes were checked by an independent colleague of the researcher. Step six reporting, resulted in this paper.

Trustworthiness criteria

Table 4 explains the strategies this study used to meet the qualitative trustworthiness criteria of credibility, dependability, transferability and confirmability (Nowell et al., 2017).

Table 4
Key strategies to meet qualitative trustworthiness criteria

Trustworthiness criteria	Strategies applied in this study
Credibility	<ul style="list-style-type: none"> • Testing and piloting the interview instrument before interviews commenced • Checking of theoretical basis, methods, and analysis with two colleagues throughout the study
Transferability	<ul style="list-style-type: none"> • Purposeful criterion and typical-case sampling • Operational data saturation throughout data collection and analysis
Dependability	<ul style="list-style-type: none"> • Logical data collection and analysis process • Creating detailed drafts of the interview protocol • Maintaining an audit trail and record of data collection
Confirmability	<ul style="list-style-type: none"> • Maintaining a reflexive research journal throughout the study • Regular meetings with two colleagues to discuss and agree progress, theoretical basis, methods, and analysis

Results and discussion

This section explores and discusses the results from the thematic analysis. From thematic analysis of the interviews, five themes were generated: familiarity, age, knowledge, interaction, and motivation. All participants mentioned each theme at least once. This paper focuses on the knowledge theme specifically, and discusses how the types of technological knowledge identified by the participants mapped onto the knowledge types explored in the literature review.

Types of technological knowledge

Participants were asked what they understood by the term technology knowledge. The participants' answers naturally grouped into three student-generated technological knowledge types, ranging from broader to more specific. Table 5 shows the three types, with a brief description and exemplifying quotes from the participants. Each type of technological knowledge was named and described with consideration given to mapping of previous literature. Due to the focus in the literature on engineering, the programming type of knowledge was difficult to name as it was not a specified type in the literature. However, it was decided that *computer science knowledge* covered what participants meant when they explained that type of knowledge. This may have been a reflection of how many learning technologies are computer-based.

Table 5
Types of technological knowledge identified from interview participants

Type of technological knowledge	Brief description	Participant quotes
Practical knowledge	Knowing how to use a range of technologies on a practical basis, general knowledge	<p>Generally, as people, we do know about a wide range of technologies, because we all use it without even realising, in our day to day life. We don't think that telly's technology, we just think it's the telly. Or we switch the radio on in the car, or in the house, and that's technology. You don't think. It's just, it's the radio, it's the telly, it's the fan, it's the ... we don't think, we just use. (Julie)</p> <p>Being able to use computers, applications, iPad, iPhones, PowerPoint, overhead projectors, basically anything that has a battery or plugs in. It doesn't even have to be portable. (Aylen)</p> <p>I know what the internet is, I know what some devices do. ... Yeah, forms [of technology]. (Anne)</p>

		<p>Knowing how to use a laptop or a computer and working your way through the internet, and how to use the internet, ... new technologies that arise that you have interest in and are curious into knowing what they are. (Bill)</p> <p>Using more slightly different types of technology, slightly different ways of using it. (Daniel)</p> <p>It's all this sort of stuff isn't it, it's being able to use all these things. All these electronic devices. (Gwen)</p> <p>All about electronic things, non-human things in our life, like the printer, or the phones, everything around me, technology. How to use it. (Chun)</p> <p>All [the younger generations] know if that, 'I know how to use this phone, but I don't know the mechanism behind it.' (Harris)</p> <p>What kinds there are, and how to use it. How to kind of on an everyday basis, like everyday usage. (Emma)</p>
<p>Structural knowledge</p>	<p>Understanding, building, being able to fix problems with technology hardware</p>	<p>Is how to fix it, like when you find some problem. (Chun)</p> <p>I think cause there's really a technical way behind it, I can imagine that it's more to do with engineering and how things fit together, cause that's what my brother is really good at. Like, he can build computers and that kind of thing. (Emma)</p> <p>Repair some online stuff. (Harris)</p> <p>When computers were 8-bit machines and we worked in DOS, and we had to manually re-image them, and we used to have to load an operating system and we used to actually have to get one computer to telnet to another computer to communicate. (Aylen)</p> <p>They do a lot of playing but they don't actually know what goes on inside the computer. (Anne)</p> <p>They ... set up their own servers. (Julie)</p>
<p>Computer science knowledge</p>	<p>Programming and software development, and the underlying principles</p>	<p>Is very professional things, how does it work, or how to development it, or something. (Chun)</p> <p>Programming stuff. Internet, website, interactive softwares, all these things is based on the feature of the very fundamental of programming. With the programming, all these things are assets. (Harris)</p> <p>It's about software, it's about programming. (Anne)</p> <p>Programming computers, and reprogramming them, and dealing with memory problems. (Aylen)</p> <p>There's knowledge like ICT kind of professional knowledge of computer science. (Sophia)</p> <p>People who are quite into coding and into computer science and stuff like that. (Bill)</p>

Mapping students' technological knowledge to the literature

The student-generated types of technological knowledge and their descriptions from this study, shown in Table 5, were compared with the types and definitions of knowledge from the literature described in Table 2. The similarity and overlap between each type of technological knowledge was assessed. The results are shown in Table 6, where the student-generated types of technological knowledge have been added to the mapping, showing how they matched with those from the existing literature.

Table 6
Mapping interview participants' technological knowledge with the literature

Hong et al., 2018	Anderson et al., 2001	van Merriënboer et al., 2002	Ihde, 1997	de Vries, 2003	Ropohl, 1997	Hansson, 2014	This study
Declarative	Factual knowledge		Knowledge about technology	Physical nature knowledge			Practical knowledge
				Functional nature knowledge			
Procedural	Procedural knowledge	Compilation		Action knowledge	Functional rules	Practical rule knowledge	
		Restricted encoding			Technical know-how	Tacit knowledge	Structural knowledge
	Conceptual knowledge			Structural rules			
	Meta-cognitive knowledge	Elaboration	Theoretical knowledge		Techno-logical laws	Techno-logical science	Computer science knowledge
		Induction				Applied science	
			Knowledge through technology				
					Socio-technical understanding		

Practical knowledge, as identified by the participants of this study, overlapped with declarative, factual, physical and functional nature knowledge, and knowledge about technology (Anderson et al., 2001; de Vries, 2003; Hong et al., 2018; Ihde, 1997), but did not extend to the types of rules-based knowledge (Hansson, 2014; Ropohl, 1997; van Merriënboer et al., 2002) that contains information about procedures and rules to achieve desired results. In fact, this rules-based knowledge was not mentioned by the participants of this study at all. This may have been due to the fact that students implicitly included rules knowledge in their ideas of practical knowledge, but did not make this explicit in their answers, or that they viewed practical knowledge as the things they knew how to do without following rules. As Julie stated, “We don’t think, we just use.”

Structural knowledge overlapped with tacit, experience-based knowledge, and procedural types of knowledge (Anderson et al., 2001; Hansson, 2014; Hong et al., 2018), as well as technical know-how and restricted encoding (Ropohl, 1997; van Merriënboer et al., 2002). It also overlapped with the structural

rules (Ropohl, 1997) about repairing technology. It was clear from the interviews that students viewed structural knowledge as something that they had to learn, it wasn't necessarily automatically picked up in the same way that practical knowledge was, and structural knowledge was learned specifically through experience. The examples given by students used in this study to create the concept of structural knowledge were quite specific experiences, and this demonstrated that the students found it a difficult concept to describe except through examples. This is consistent with tacitness.

The third type of knowledge identified by students, computer science knowledge, overlapped with Hong et al.'s (2018) procedural knowledge in a similar way to structural knowledge, and both computer science knowledge and structural knowledge seemed to be two subsections within the larger section of procedural knowledge. It also went beyond procedures into concepts, therefore mapping onto conceptual knowledge (Anderson et al., 2001) as well. Computer science knowledge mapped almost exactly onto technological science (Hansson, 2014; Ropohl, 1997), perhaps because to its focus on technological solutions.

In addition to mapping onto the other types of knowledge including the knowledge dimensions from Bloom's revised taxonomy (Krathwohl, 2002), the three types of technological knowledge identified from students' comments were also mapped onto learning structures, in particular Bloom's revised cognitive process dimensions (Anderson et al., 2001). Practical knowledge mapped onto the remember, understand, and apply levels. This type of knowledge is about the application of commonly-used and using-without-thinking knowledge. In turn, this level of automatic application comes from remembering and understanding how to use a wide range of technologies, and therefore students implicitly generalise their current knowledge to new technologies.

Structural knowledge was mapped onto the levels of understand, apply, analyse, and, to some extent, evaluate. Understanding the physical processes behind technologies is very much a part of application, and thus this type of knowledge covers both of these aspects of Bloom's revised taxonomy (Anderson et al., 2001). Furthermore, analysing is about inspecting, differentiating and organising components (Anderson et al., 2001), which is a crucial skill in allowing the user to apply their knowledge and understanding to hardware and fixing problems. Structural knowledge also, to some extent, mapped onto evaluate, as evaluation of a technological problem to determine the best solution is important to do before one can act upon it. However, it is only a partial mapping to this cognitive domain, since one doesn't necessarily have to be able to evaluate effectively or at all in order to, for example, fix a computer problem. Many problems can be fixed simply through trial and error, which is more of an analytical skill than an evaluative one, and knowing what to fix may lead the user to try a single solution that has worked for them before, which again, is not so much an evaluative solution as one from prior experience in application.

Finally, computer science knowledge was mapped onto both the evaluate and create levels. Evaluation can be about making judgements about a process (Anderson et al., 2001), in this case a technological process, and these judgements are required in order to create a solution. Computer science knowledge include programming and software development, and these are very creative endeavours requiring high-level evaluative skills (Kiesler, 2020). It is worth noting that practical and structural knowledge are often prerequisites for computer science knowledge.

Table 7 shows the diagrammatical mapping of the student-led types of knowledge onto Bloom's revised taxonomy (Anderson et al., 2001). The fact that this mapped onto Bloom's revised taxonomy shouldn't be surprising, as the question asked was about knowledge, which by definition should map onto these cognitive domain structures. However, it may indicate some degree of trustworthiness of the results.

Table 7
Mapping of Bloom's revised taxonomy (Anderson et al., 2001) cognitive domain structures and the three types of student-generated technology knowledge

Create			Computer science knowledge
Evaluate		Structural knowledge	
Analyse			
Apply	Practical knowledge		
Understand			
Remember			

Implications

It is important for educators to understand the knowledge that underpins students' use of technology. It has been shown by this study that this knowledge is often tacit, learned through experience and exploration, and rarely consciously considered (Dinur, 2011; Hansson, 2014). Students tend to think in terms of what they can do, rather than how they know how to do it. This was shown by the participants' generation of practical knowledge, which they viewed as using a range of technologies, and structural knowledge, where they commented on experience-driven understanding of hardware. Although these types of technological knowledge cover the understanding, analysing and, to some extent, evaluating aspects of Bloom's revised taxonomy (Anderson et al., 2001), these are rarely conscious activities. The onus, therefore, falls on the educator to understand how students are structuring and scaffolding their knowledge and to use this understanding to design learning activities and pedagogies that meet the objectives of the course (Coleman, 2017).

The mappings conducted in this study can also be used to see not only what the student-generated types of technological knowledge are, but also where there are gaps. Although other studies have no empirically-derived knowledge types from students, there is value in comparing the types of knowledge found by educators with those suggested by students, particularly across disciplines. This comparison will elucidate the gaps in how students view and articulate their understanding of technological knowledge. This in turn will help educators to address the gaps by seeing where previous authors' types of technological knowledge exist, and tailor classroom activities to explicitly develop students' knowledge to cover those gaps.

Higher-order knowledge types are built upon a foundation of factual knowledge, and educators should assist students to do this building and construction (Barak, 2013). This is then also true of practical knowledge, as found in this study. All students have some form of practical knowledge of learning technologies, whether through the personal use of mobile phones, laptops, or software like email and games, and this was evident in the wider context of both the survey preceding the interviews and the interviews themselves in this study (Staddon, 2020). Educators can therefore use students' practical knowledge of familiar technologies to build and develop their competencies in new forms of technology, for example by introducing the use of voting mechanisms, such as clicker devices or Kahoot!, as extensions of the use of mobile phones or laptops. A more complex example may be that educators can explain virtual or augmented reality in the context of games such as Pokémon Go or the haptic feedback students experience when tapping on their mobile phones. This extension of students' current knowledge to new forms of technology is particularly important when students are having to learn quickly, for example for technology-based assessments, or during events when students must rapidly pivot to online learning. For example, although COVID-19 may seem like a unique event, the lessons educators have learned about moving students to online and at-home learning are invaluable and will almost certainly inform decision making in the future (Fitzgerald et al., 2021).

Structural knowledge about techniques and understanding hardware specifically builds on the students' practical knowledge. Both practical and structural knowledge were heavily experiential, based on the students' comments during this study. Knowing that practical and structural technological knowledge types are based in experience and are mostly tacit can help educators arrange activities that are also practical and experience-based, allowing students to develop their skills in these areas, such as running virtual lab experiments, or simply just using a certain piece of software such as SPSS. Simultaneously, educators should also work with students to extrapolate procedures and rules to help students generalise their technological knowledge to the rule-based knowledge gap. Examples may include prompting students to notice the procedures they are following day-to-day when, for example, opening and closing a familiar piece of software, or choosing the correct tools for a particular activity, such as designing their own study technique. Otherwise engaging with logical and analytical thought processes underlying the student's own technological learning is also important. When students actively notice how they open software, or choose techniques, they can start to apply those skills to new software and new choices, deepening their knowledge of how technology and their own learning functions, as in Ropohl's (1997) structural rules. Bridging the gap between learning technology experience and underlying theory is particularly important to enable the development of pedagogically-sound learning strategies (Broadbent & Poon, 2015). These are transferable skills that students can utilise beyond the use of learning technologies. Additionally, the explicit extraction of procedures and rules for students will increase students' awareness of these types of technological knowledge, compilation (van Merriënboer et al., 2002), rules (Hansson, 2014; Ropohl, 1997) and action

knowledge (de Vries, 2003) specifically, addressing the gap between the current practical and structural knowledge types found in this study.

Computer science knowledge, as defined by the participants in this study, was possibly the most specialised type of knowledge in the student-generated taxonomy. It is applicable mostly to those who study software-based subjects where they may be asked to write code. Students who have computer science knowledge are likely to already have strong practical knowledge skills, although only some of them may have high structural knowledge levels. The study participants focused a lot on programming as a key part of computer science knowledge. For students who are required to programme, for example in a computer science course itself, using R or Python in the social sciences, or using data from social media generally (Amaya et al., 2021), it is important to also consider this level of technological knowledge in order to target the learning and assessment materials provided and differentiate it from the other knowledge types. Further, this type of knowledge is applicable to converting between abstract representations of information such as tables and symbols into real-world applications (Barak, 2013). Knowing computer science knowledge was considered a useful technological knowledge type by students. This means that educators can use the mapping to judge where the gaps in students' perceptions of technological knowledge lie. For example, beyond computer science knowledge there are concepts of elaboration, induction (van Merriënboer et al., 2002), theoretical knowledge (Ihde, 1997), and metacognitive types of knowledge (Anderson et al., 2001; Ihde, 1997; Ropohl, 1997). These may be considered less useful when it comes to student engagement with learning technologies, but it is still useful for the educator to be aware of these knowledge types and to consider whether their particular students would find it useful to stretch their understanding in this way. This is particularly the case for metacognition, which in general has positive effects on self-regulation and academic success (Broadbent & Poon, 2015).

Limitations

This study had a number of limitations. The student participants were from one UK Russell Group institution, and therefore the results may not be transferable to other institutions of different types or from different locations. This study used a very small sample size. While code saturation was taken into account for the purposes of this study, the small sample may mean that complexities in the level of definition between technological knowledge types may have been obscured.

Aspects of common technological knowledge types that were not covered by the student-generated definitions of technological knowledge, such as metacognition, induction, rules and procedures, and application of theoretical concepts, may have been a function of the relatively small sample size, the focus of the interview, or, most likely, the limitations of asking students who were generally concerned with what they knew and not about the underlying knowledge structures behind their knowledge. As a result, the three types of student-generated technological knowledge suggested by the taxonomy presented in this paper do not exhaustively cover or replace other types of technological knowledge, but they do supplement them, and most importantly, reflect the way that students think and where the gaps in their thinking lies. Ascertaining the structure of student thought is an important but difficult aspect of education, as only then can educators target their teaching and activities to individuals.

Future work may include conducting a larger-scale survey to get a larger sample of students' perceptions of technological knowledge. Additionally, there may be value in focus groups where the students can gather and discuss their collective opinions and name the knowledge types themselves.

Conclusion

Whereas previous studies on technological knowledge have been educator-led, this study explored students' perceptions of technological knowledge. These student-generated types of technological knowledge were mapped onto existing technological knowledge taxonomies, as well as general knowledge structures such as Bloom's revised taxonomy. There were however, a number of gaps in how students defined technological knowledge. These gaps can be elucidated by mappings such as this study. Knowing about the types of technological knowledge that students perceive can allow educators to target their teaching depending on the knowledge level they wish to generate with their learners, as well as explicitly targeting gaps in their students' knowledge. This is particularly important since UK universities require students to be fluent users of digital technologies.

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Appendix A Interview protocol

Opening:

1. [Establish rapport] Welcome, I'm Rachel. How are you?
2. [Purpose] I would like to ask you some questions about your experiences with technology-enhanced learning, following on from the questionnaire you did online. I'm hoping this will help lecturers and tutors use technology better.
3. [Timeline] The interview should take about half an hour, is that okay with you?
4. [Sign 2 consent forms and obtain permission to audio record – begin recording]
5. [Structure] I'm hoping to talk to you about what you understand by technology-enhanced learning, what you enjoy, your confidence

Starting the conversation – concepts:

1. What do you understand by the term technology-enhanced learning?

Enjoyment:

1. Do you generally enjoy using technology for learning?
2. Do you enjoy using technology generally?
3. Which forms of technology are the most enjoyable to use for learning?
 - a. Why?
4. Which forms of technology are the least enjoyable to use for learning?
 - a. Why?
5. Which forms of technology are the most enjoyable to use for your personal use/non-course activities?
 - a. Why?
6. Which forms of technology are the least enjoyable to use for your personal use/non-course activities?
 - a. Why?

Confidence:

1. How confident would you say you were with technology?
 - a. On a scale of 1 to 10?
 - b. Why?
 - c. What affects your confidence with technology?
 - i. If something goes wrong?
2. Which forms of technology are you the most confident using? (from list from Section 1 of the questionnaire)
 - a. Why?
3. Which forms of technology are you the least confident using? (from list from Section 1 of the questionnaire)
 - a. Why?
4. How confident would you say you were when *learning* about technology?
 - a. On a scale of 1 to 10?
 - b. Why?
 - c. What affects your confidence when learning about technology?
5. Do you feel you need support for the technology you are using?
 - a. Do you seek support if you need it?
 - b. Who from?
6. Are you ever anxious about technology?
 - a. Why?
 - b. When are you most anxious?
 - i. Before using it?
 - ii. During using it?
 - iii. After using it?

Knowledge:

1. Do you have any ICT, computing, or other technology qualifications?
 - a. Which qualification? GCSE/O-level/etc
 - b. When did you get the qualification, roughly?
2. What do you understand by 'technology knowledge'?
 - a. Do you feel knowledgeable about technology?
3. How knowledgeable do you feel you are about technology compared to:
 - a. Other people your age?
 - b. People younger than you?
 - c. People older than you?
 - d. Your friends?
 - e. Your family?
4. Which technologies did you use before coming to university?
 - a. Which were introduced to you by the university?

Closing:

1. [Extra info]
 - a. Is there anything else you think it would be helpful for me to know?
 - b. Anything else you would like to add?
2. [Maintain rapport] Thank you very much for the time you took for this interview. As agreed, you will be entered into a draw for the £10 Amazon voucher. [Give them one consent form to keep]
3. Would it be okay if I contacted you if I have any more questions?
4. Thank you again.