Chapter 11
Investigating School Students' Knowledge About Technological Systems: Towards "Qualities of Knowledge"

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Abstract Technological systems as a school curriculum component is complex, under-developed and under-researched. In this chapter, we present results from an investigation of school students' knowledge about technological systems, hypothesizing the occurrence of different "qualities of knowledge". A test instrument was distributed to 26 groups of students (n = 56) in a Swedish grade eight class (14–15 year olds), and data analysis was carried out using a qualitative, hermeneutic method. The findings show that the students' qualities of knowledge regarding the overall structure of the systems was quite advanced, but the systems or the societal context were not elaborated upon with any detail. The purpose of the system could be connected to humans and society, but students did not offer a description of the overall purpose. The flows that the students described were only of matter (water, wastewater) but not energy or information. The system boundary was also elusive, except for waste coming out of the sewer system and other environmental consequences. Thus, the test instrument was useful to gauge students' qualities of knowledge, especially regarding system structure, but with respect to some other system aspects the validity might need to be further improved.

Keywords Technology education · Technological systems · Secondary school · Qualities of knowledge

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11.1 Introduction

Teaching about technological systems is nowadays mandated in many school curricula and standards around the world (e.g., ACARA, 2017; ITEA, 2007), but it is still a challenge for technology teachers. Previous research in Sweden shows that the learning demands on students from some teachers was low and not at the level required by the curriculum, which presumably has to do with an insufficient understanding of systems even among teachers (e.g., Schooner et al., 2018). This may stem not only from the inherent complexity of technological knowledge (Mitcham, 1994; Vermaas et al., 2011) but also from the short history of technology education and the less developed teaching practices. Furthermore, technological systems as a curriculum component is complex, under-developed and under-researched. Even though the previous research is rather limited, a few conclusions about students' and teachers' understanding of technological systems can be drawn. Firstly, both students and teachers are better at understanding structure, input and output of a system than its behaviour. Control mechanisms, feedback and flows of information are particularly difficult to grasp. Secondly, students understand systems better when they are scaffolded by, e.g., teachers, and thirdly, students develop a deeper, more complex understanding of systems as they grow older, especially regarding the included components. Finally, the role of humans in and around technological systems is difficult to understand, probably because humans fulfil so many different roles as designers, users and operators and thereby function as crucial but multifaceted components of the systems (e.g., Hallström & Klasander, 2017; Koski & de Vries, 2013; Mioduser et al., 1996; Örtnäs, 2007; Svensson, 2011).

However, there is as yet no agreed upon template for what constitutes qualitatively different knowledge of technological systems, although Svensson et al. (2012) did formative research towards this end. In this chapter, we present results from an investigation of school students' knowledge about technological systems, hypothesizing the occurrence of different "qualities of knowledge". The investigation utilizes empirical research data from an exploratory Swedish school development project aiming at better understanding different aspects of students' knowledge of technological systems, through a broad array of examples of systems.

Swedish technology education has shifted quite significantly in emphasis, content focus and teaching methods over the last four decades. The subject evolved from being a male-dominated optional school subject in lower secondary school, via a compulsory component in a more interdisciplinary subject area where technological aspects were linked to natural sciences, to a redirection in 1994 when the school subject technology got its own national curriculum, from year 1 to year 9. This also meant that the sociotechnical dimensions—the relations between technology, society and nature—were strengthened and that studies about technological systems got a special component in the curriculum that is still central (Hallström, 2009). However, even if the investigation is set in a Swedish national context, we argue that the findings are relevant to discuss in relation to an international technology education audience and context.

11.2 Definitions and Methodology

When learning about technological systems, some aspects are considered by students to be more difficult than others. For example, visible components in a system are easier to understand than abstract, invisible phenomena such as feedback loops or system borders, and linear systems are better understood than nonlinear systems (e.g., Arbesman, 2017; Hallström & Klasander, 2020). In order to further explore how students understand technological systems, we constructed test instruments that built on hypothesized qualities of knowledge about technological systems. A technological system can be defined as a purposeful collection of components or sub-systems, connections and flows between them, and a system border that delimits the scope of the system. From this foundation, the test instruments were designed to incorporate a broad array of aspects on system knowledge, which was based on theories of technological systems and supposed to give students opportunities to reflect upon and express, e.g., their knowledge of the functions of certain technological systems, how they are delimited, what components they include, what kind of resources that flow through the systems, the systems' relation to their surroundings, the systems' historical change, interaction between components, how the systems are controlled, etc. (e.g., Bijker et al., 2012; Hughes, 1983, 2004; Ingelstam, 1996, 2012; Klasander, 2010; Vermaas et al., 2011).

Related to the above definition, we included altogether four different aspects of technological systems, and in these, we hypothesized that different qualities of knowledge could manifest:

1. *System boundary and relation to the surroundings:* every system has a system boundary, by which it relates to a surrounding which can include other humans, nature etc.
2. *Purpose of the system*: for every system, one can identify one or several purposes.
3. *System structure and behaviour (modelling)*: the structure of a system can be described as made up of components with relationships between them.
4. *Resource flows in the system:* in every system, there are different flows of energy, matter and information (cf. Hallström & Klasander, 2017; Schooner et al., 2018; Svensson et al., 2012).

The above four aspects of technological systems knowledge can be regarded as building blocks in a solid understanding of technological systems, and in this sense, they are not hierarchical but rather complementary.

Within each aspect, however, there is an increased complexity of knowledge, of which some but not all elements may be needed for a higher order of understanding of technological systems. We thus define "qualities of knowledge" as stages or phases of an increased complexity of systems knowledge (cf. de Jong & Ferguson-Hessler, 1996; Friege & Lind, 2006). This way of thinking about increased knowledge depth or complexity shares certain similarities with the structure of the observed learning outcome (SOLO) taxonomy. It also describes knowledge qualities in the sense of increased complexity and focus on quality, from unstructured to generalizable knowledge—unistructural, multistructural, relational and extended abstract (e.g., Biggs & Collis, 1989; cf. also Wilson, 2009).

The research reported in this chapter used test instruments that contained some 20 different assignments, between two and five sub-questions each. The assignments could be focusing on, e.g., water supply and sewerage, the national electric grid, cars and road transport, smartphones, elevators, GPS or electric ovens. The test instruments were varied regarding different types of technological systems and distribution of present-day and historical examples. In this regard, we included different "starting points" for the examples of systems in the test instruments, in order to test various qualities of knowledge about technological systems. One of the starting points is the interface between the supposed system and the human beings using it, for example, a toilet, a smartphone or an ATM machine. Another starting point is a fairly well-known technological system, e.g., the railway system, and then, one moves from that wholeness and successively identifies important sub-systems and components. A third starting point is following the historical change—forwards from a prior point in time, or backwards from now—of a well-known and agreed upon technological system (Hallström & Klasander, 2020).

For this investigation, one particular test instrument about water supply and, by extension, sewer systems was employed (see Fig. 11.1, the House). The test instrument, the House, was arranged with four sub-questions (a-d) supposed to give the students opportunities to express answers showing different technological systems aspects (1–4) for the freshwater and sewerage systems centred on the house. Table 11.1 outlines what kinds of aspects (1–4) were meant to be gauged in the four sub-questions (a–d) of the test instrument.

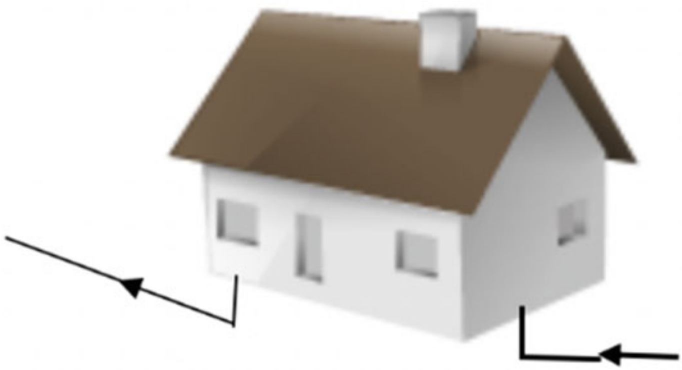

Fig. 11.1 Image of the house, used in the test instrument to visualize and scaffold the students when answering the sub-questions

Table 11.1 Outline of the focus of the sub-questions (a–d) of the student test instrument about water supply and sewerage systems, in relation to the aspects of technological systems knowledge (1–4)

The sub-questions in the test instrument: the House	Built-in aspects of technological systems knowledge in the test instrument
(a) What is the freshwater system for? What important needs of the inhabitants of the house can the system fulfil?	Purpose of the system (2)
(b) What is the freshwater system for? What important needs of society can the system fulfil?	Purpose of the system (2)
(c) How does the freshwater system work? Start with drawing a simple image of the freshwater system. Exemplify with some parts of the system that you think are important and describe how these work together	System boundary and relation to the surroundings (1); Purpose of the system (2); System structure and behaviour (modelling) (3); Resource flows in the system (energy, matter, information) (4)
(d) Does the freshwater system have an impact on the environment? If so, how?	System boundary and relation to the surroundings (1)

11.3 Research Methods

To try out the test instrument with school students, we contacted teachers connected to the CETIS (Swedish National Centre for School Technology Education) national network of technology educators, in order to see if they were interested in participating in this project. Through word of mouth, we got a positive response from two secondary schools in a mid-sized Swedish city, so the sampling method used was so-called snow-ball sampling (Robson & McCartan, 2016). The test instrument about technological systems was subsequently distributed in two mixed-gender grade eight classes (14–15 year olds) consisting of 26 groups of students ($n = 56$). Altogether 26 copies of the test instrument "the House" were thus filled in by the students in these secondary school classes. The students worked in pairs or in groups of three selected by the teachers. The teachers made sure that the students could work for as long as they needed to be able to finish filling in the assignment/the test instrument; this took approximately 45 to 60 min.

A hermeneutic, qualitative method of analysis was employed when coding and categorizing the data, that is, single student texts and images were related to the whole body of texts and images, the four systems aspects, and the systems context in a reciprocal, re-interpretive way (Ödman, 2007; Robson & McCartan, 2016). Since a part of the data was made up of the students' drawings of components and systems, often with textual comments, we thus employed so-called iconotextual analysis—hermeneutic analysis of text and image in combination—in the analytical process (cf. Axell, 2015; Ihde, 1990). The analysis of the student data was performed based on the Swedish transcripts. Excerpts that are included as particularly illustrative examples were translated into English by the authors.

The hermeneutic-qualitative analysis was performed in stages, where each stage of the analysis led to a deeper understanding of the data. First, an initial reading of the whole data set was performed, whereafter further readings were carried out in conjunction with initial coding and subsequent categorization. Thereafter, student answers were further scrutinized in relation to specific aspects of technological systems knowledge (1–4) (see above and Table 11.1). The student answers were subsequently evaluated in terms of their qualities of knowledge under each aspect, focusing on the *differences* between increasingly more complex qualities. At this stage, we also investigated the potential of the SOLO taxonomy to inform the analysis of the students' answers in relation to qualities of knowledge. The presented findings constitute the collective picture of the students' knowledge of systems aspects of the water supply and sewerage systems.

The validity of the study was ensured by building the instrument and the analysis on previous studies (e.g., Svensson et al., 2012), and by carefully trying out the questions in several stages, with several actors contributing to the validity at each stage. Our results can only be seen as representative of the 26 groups of students, although we hope to generate inter-subjective validity through them (Larsson, 2005).

Throughout the research process, the ethical principles for research were followed. The teachers and participating students consented to participation, after having been duly informed about the investigation in line with ethical guidelines (Swedish Research Council, 2017).

11.4 Student Qualities of Knowledge

Our findings are here presented with respect to students' potential qualities of knowledge, in relation to increased complexity from unstructured to more relational and generalizable knowledge—in line with the SOLO taxonomy.

1. **System boundary and relation to the surroundings**

Questions in the test instrument involving the aspect of system boundary and relation to the surroundings offer possibilities not only to clarify the system as such, but also to relate it to the surroundings and other systems with increased complexity as the system is described not as isolated but as both having a kind of boundary and relation to other systems, both natural and technical.

Most student answers did not show a demarcation or imply a system boundary. One example of this is shown in Fig. 11.2.

There were answers which defined a system border, but at the same time, they also misconstrued the connection between the water system and the sewerage system by suggesting that the wastewater from the house goes to the wastewater plant and then directly back into the freshwater system. One example is presented below in Fig. 11.3:

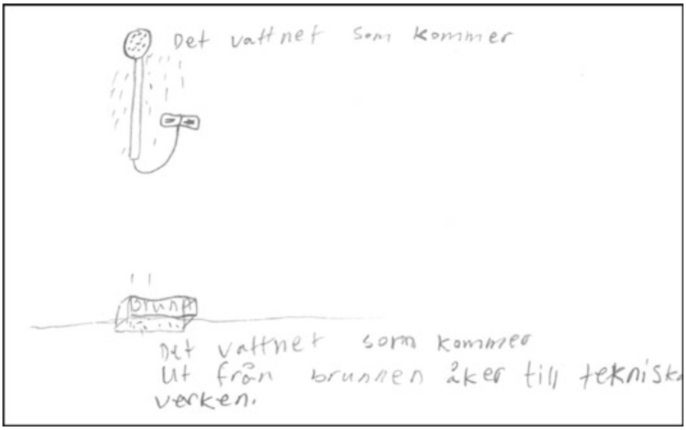

Fig. 11.2 Example of a system drawing without system boundary, showing a shower nozzle and a bathroom floor drain with accompanying text: "The water coming in […] The water that is discharged from the floor drain goes to *Tekniska verken* [municipal wastewater plant]."

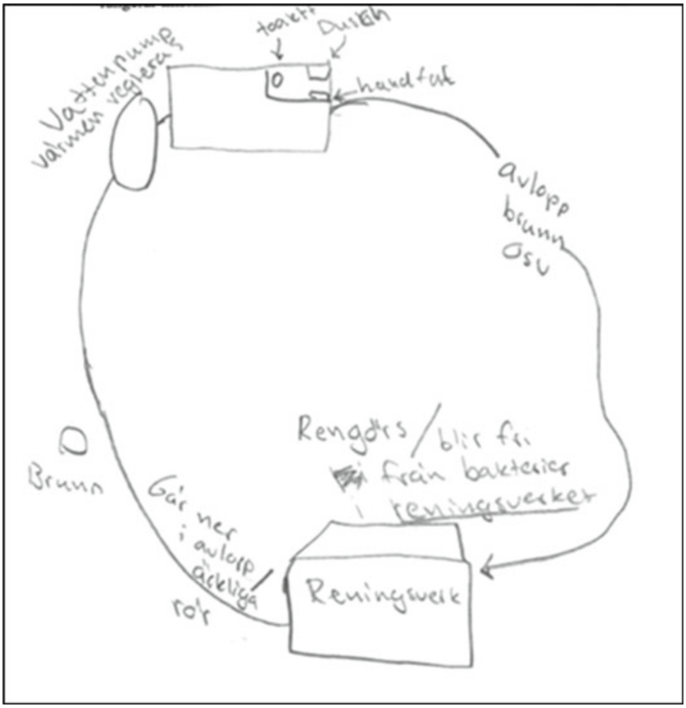

Fig. 11.3 Example of a system drawing of a closed loop between the water and sewerage systems. There are examples of miscellaneous components such as shower, sink, toilet, street drain, wastewater plant and pump

In reality, the purified wastewater is discharged into a nearby waterway and has to be purified again in a freshwater plant before it is fed back into the water supply system.

Most answers did not relate the system to its surroundings at all (see e.g. Fig. 11.2), thus showing low complexity. A few answers, on the other hand, related the system to other "systems", such as society and nature, showing both multistructural and relational features. Of these, most answers described negative influence in the form of various kinds of pollution:

> Yes, it affects nature in that particles are dissolved in the water [and] are discharged into the environment. Fish can get sterile from contraceptive pills. When farmers fertilize vegetation grows. When we build pipes we destroy a bit of nature.

There were also a few groups who included positive effects, for example:

> Water is discharged into the lake when it is clean, and then the animals can drink from the lake.

In summary, the student answers concerning this first aspect thus varied a great deal in complexity, with a predominance of less complex answers that did not recognize any system boundaries at all. However, some answers were more complex in recognizing system boundaries and even other technological and natural systems, although the relations described were mostly negative, for instance, various kinds of pollution in the environment.

2. **Purpose of the system**

When it comes to describing the purpose of the water system, we wondered if and how students described this in respect to the individuals in the house and to society. The questions addressing this aspect offer different possibilities to show the complexity in the purposes. For example, understanding the purpose for society involves more complex knowledge than the purpose for individuals.

Almost every student answer included that the purpose was to *provide* water to houses and society (fire brigades, swimming pools, factories, etc.):

> It is there to provide the residents with potable water and water for other needs. Washing, doing dishes, toileting, drinking, cooking, heating.
>
> The water system is there to provide clean water, to the drain, to fire hydrants to be able to put out fires. To swim in swimming pools. Sprinklers. To be able to make ice to ice rinks, for example. To hospitals/residential areas/apartments etc.

An observation from the analysis of the students' answers is that they were focused on giving *examples* on what the incoming water should be used for. All answers mentioned washing, almost every answer mentioned food preparation, but relatively fewer included heating. On a societal level, the examples were broader and fairly equally distributed between water used for fire brigades, hospitals, swimming pools, production companies, shops, heating, refuse collection and cleansing, water towers, schools and flooding. In summary, most answers focused on the input of water to

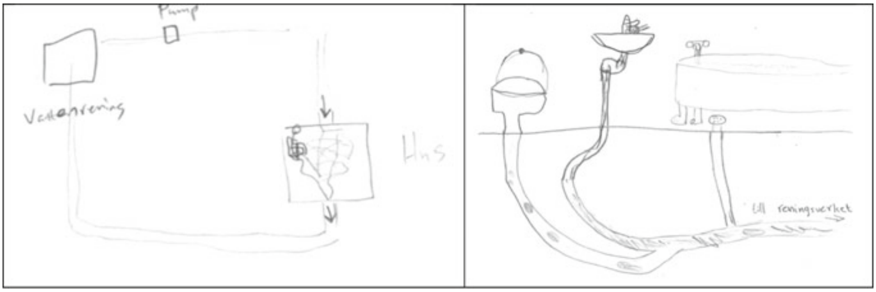

Fig. 11.4 Drawings of water systems with a few components; house, water treatment and pump in the left drawing by one group, and "to the water treatment plant" in the right by another group

houses and cities, rather than output. The examples given were richer on the societal level.

A minority of the answers described a purpose in terms of *leading away* water from houses; even fewer answers brought up discharge from parts of the city such as drains, wastewater and sewerage. Some indications on such purposes could, however, be found in the students' drawings, although not explicitly (see, for instance, Figs. 11.3 and 11.4). Some written examples of the purpose of leading away superfluous water are also given below:

> For everyone to get water and get rid of feces in sewers.
>
> There are in drains, basins to remove excess water that is later reused in purified form.

In summary, the complexity of the answers was fairly low regarding the purpose(s) of the water system. In relation to the use of resources, in terms of matter, mostly *freshwater* was mentioned. A few answers, however, stated that one purpose of the water system is related to providing *energy*, thus showing some example of a more complex reasoning:

> The water system is for heating the house through radiators and district heating and maintaining hygiene with hot water…

3. **System structure and behaviour**

The question that relates to this aspect gives students possibilities to both model the technological system and explain how it functions. The increase in complexity entails explaining relations between components in the system and how their behaviours influence different parts of the system as well as its purpose.

Regarding the most basic knowledge about a system's structure and behaviour, the majority of student answers exemplified components and specified relationships between components in the water and sewer systems. Two examples are shown in Fig. 11.4.

However, specifying how the components relate to the behaviour of the system was less well described by the students; here they were either vague about the relationship between components and the system as a whole, or they described a small part of

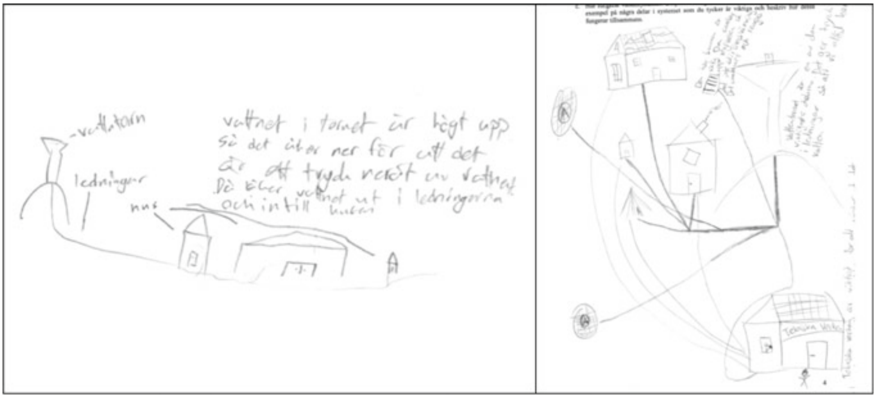

Fig. 11.5 Drawings of water systems with components relating to behaviour of the system. To the left one group writes: *"The water in the tower is high up so it goes down because there is a downward pressure of water. Then the water goes out into the pipes and into the house."* To the right another group writes *"…The water tower is one of the most important parts. It puts pressure in the pipes so we always have water…"*

the system (see e.g. Fig. 11.5). Fewer groups managed to show this quality than the previous, less complex ones.

The drawn models were of varying complexity, where a third of the answers included none or irrelevant models. Another third incorporated simple or incomplete models with few components (see Fig. 11.2), including several misconceptions. The remaining answers provided system models, of which one was a verbal model and the others visual (cf. Gilbert, 2004). Below is an example of a verbal model/analogy:

> A water system works like the blood system. […] The heart is like a water tower that keeps the pressure up all the time. The capillaries are like the system that pumps water.

Of the visual models, most were input–output models, but only a few of them also of a more complex network kind, such as Fig. 11.6.

This was also the only answer deemed to reach the more elaborate knowledge quality, to describe how changes to components/sub-systems influence other components as well as the purpose of the system. Thus, most of the models were basic such as of the input–output kind but lacked the more intricate descriptions of networks of components, and there were also some misconceptions such as in Fig. 11.7 below where purified wastewater feeds directly back into the freshwater system.

When summarizing the answers concerning this third aspect, we see a great variation. Most answers were of low complexity dealing only with components and relations between them. Of those that presented a drawing, few presented system models and only one of them reached a higher complexity in terms of the system's parts also influencing the purpose of the system.

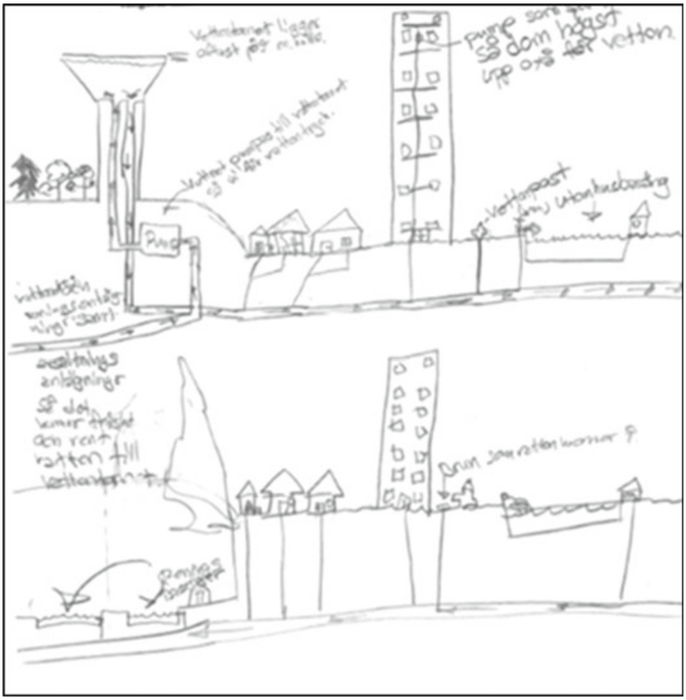

Fig. 11.6 Example of a system drawing showing the visible components as well as the pipe networks under-ground

4. **Resource flows in the system**

The aspect of resource flows is linked to the same problematic as the former aspect, to draw a model of the system and explain how the system functions. The increasing complexity, however, is about more abstract resource flows than matter, namely energy and information, for instance, how flows of information are used to control the system.

Not surprisingly, many students described flows of matter in the form of water. They described in words and/or pictures how the water flows from the freshwater plant and water tower through pipes to the house, and a few also depicted how wastewater is discharged from the house and goes to the wastewater plant. See Fig. 11.8 for two examples.

The students did not, however, describe flows of energy or information nor how these flows are used in the system, with one exception. One group correctly observed that hot water carries energy, although it is unclear if they mean hot water input into the house (in which case this really comes from district heating systems) or within the house (from e.g., a home heating system):

> The water system exists for us to be able to reuse the water again and again, and even be able to control the temperature. That is, get heating to the taps, etc.

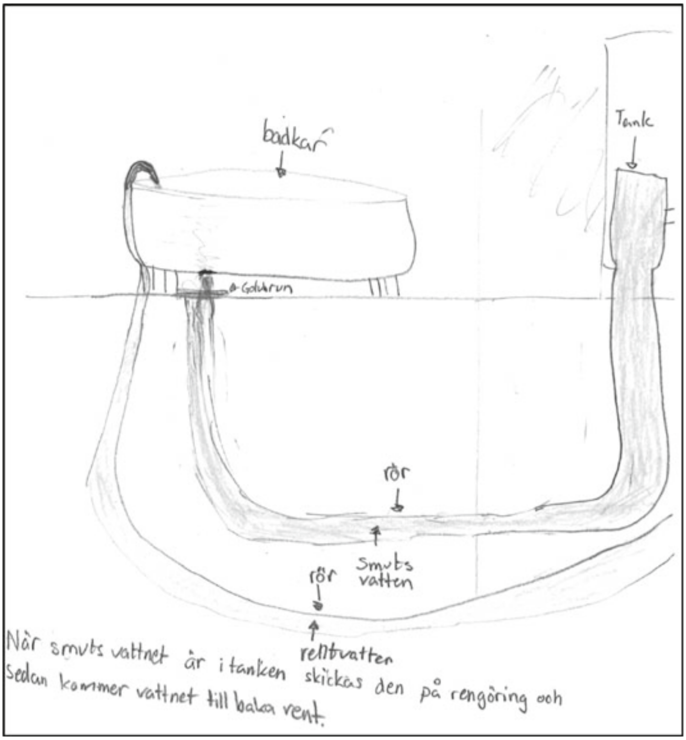

Fig. 11.7 Example of a system drawing of water and sewer pipes in the house where it is implied that purified household wastewater feeds directly back into the freshwater system

Fig. 11.8 Drawings of water systems only showing flows of matter (water). To the left is a drawing from one group, and to the right from another group that also writes: "*The water tower conducts water and pressure. Water in the shower otherwise you smell like shit. Fires are extinguished by water, otherwise, society burns down. Toilet needs water for poop and pee to be flushed down.*"

In summary, the answers about the fourth aspect, resource flows in the system, dealt only with concrete flows (water) and thus were of low complexity. None of the answers dealt with flows of information and only one answer mentioned energy, however not in terms of flows.

11.5 Summary

The findings indicate low levels of complexity related to the qualities of knowledge about a technological system. However, there were differences depending on the aspect. Regarding the **structure and behaviour** of the system, the answers were more complex than for other aspects, showing both knowledge of components and relationships between them, as well as some knowledge about how to describe the model and relating components to system behaviour. Regarding the **purpose** of the system, many examples were given about purpose both for humans and society but not related to resource flows or to other possible purposes. When it comes to the **system boundary and relation to the surrounding**, it was evident that boundaries seldom were described but some examples of relations to nature (often negative) were exemplified. No relationships with other systems were mentioned. The answers of the lowest complexity dealt with the aspect **resource flows** where the answers described flows of matter (water) but not flows of more abstract entities as energy and information. Neither were there descriptions of how energy is used within the system or how information is used to control the system.

11.6 Concluding Discussion

In this chapter, we present results from an investigation of school students' knowledge about technological systems, hypothesizing the occurrence of different "qualities of knowledge". The findings from the 26 groups of students reveal that the students have some knowledge of technological systems, but that it varies depending on the system in question and what aspects we are talking about. Especially regarding the aspects purpose and resource flows of a system, the students often did not show more complex qualities of knowledge, which we interpret is either because the teaching was not advanced enough or that our probes, the test items, did not allow them to express such understanding. For example, we only asked about "the water system" not "the water and sewer systems", while the figure in the test instrument shows arrows for both input and output (see Fig. 11.1) and the students sometimes referred to sewerage in their answers.

When the students answered, for example, the question about the purpose of the water system for the individual they often exemplified by mentioning activities (take a shower, drink water and flush the toilet), but they did not explicitly write about the purpose and main function of the water system. Our position when interpreting the student answers is thus parallel to the teachers' because we both try to identify if the student has shown his or her understanding of the purpose, etc., of the water system as a whole.

Consequently, the students showed quite advanced qualities of knowledge regarding the structure of the system, and some students could draw quite detailed systems near the house with freshwater plants and water towers. However, the systems within the home were not elaborated upon with any detail, nor was the wider societal context. The purpose of the system could be connected to humans and society, but students did not offer a definition of the overall purpose. The flows that the students described were only of matter/water, not energy or information, so there was no notion of the driving forces or control of the systems. The system boundary was also elusive, except for waste coming out of the sewer system and other environmental consequences. All in all, the reported investigation thus confirms much of previous research (e.g., Hallström & Klasander, 2017; Koski & de Vries, 2013; Mioduser et al., 1996). Thus, the only one of the four aspects of technological systems that seems to have "worked" is system structure and behaviour (#3), although students generally did not reach the most advanced qualities. Regarding the other three aspects (#1, 2 and 4), however, students never reached beyond the less advanced knowledge qualities (for a discussion of limitations of the investigation, see Hallström et al., 2021).

The description of depth or complexity of students' technological systems knowledge can also be conceptualized in line with the SOLO taxonomy. We therefore want to explore the possibility of relating the qualities of knowledge that we identified under each system aspect to the categories of the SOLO taxonomy. In Table 11.2, we show visually with colours where the most answers could be "located" in relation to four of the SOLO categories. The darker the colour, the more answers in the category. No colour at all means that none or only one single answer could be identified.

11.7 Implications

The reported investigation thus shows that school students' knowledge of technological systems seldom extends beyond the unistructural and multistructural SOLO levels. In actual fact, the teachers divulged that the participating students had not been taught about the water system in houses or society, and one student wrote: "This was the first time I heard the word 'water system'". In the textual answers and drawings, we could, however, see that the students had been educated about how a water tower works and how it distributes pressure in a system. We suppose that this might have been more a part of previous teaching in other subjects than technology. Students were also presumably taught about environmental pollution within science but not very much about the technological aspects of systems. Therefore, in order for the students to be able to develop more complex qualities of knowledge, they need to be taught more about technological systems (cf. Booth Sweeney & Sterman, 2007; Hallström & Klasander, 2017).

Table 11.2 Application of SOLO categories on four aspects of technological systems and the approximate abundance of student answers in different categories

	SOLO categories			
Aspect /quality	**Unistructural**	**Multistructural**	**Relational**	**Extended abstract**
1. System boundary and relation to the surrounding	No boundary described	Describe boundary	Relate to the system's surrounding: humans, society, nature and other systems (interdependence between systems)	Relate to several other systems and compare systems with similar purposes
2. Purpose of the system	Relate purpose to humans	Relate purpose to society	Relate purpose to use of resources (energy, matter, information)	Describe how questions about the purpose of the system can be answered on a systemic level (e.g. that it is possible to find several purposes of a system)
3. System structure and behaviour (modelling)	Exemplify components	Describe relationship between components	Relate components to system behaviour and describe the system using relevant model (e.g. network, or cyclical, model, hierarchical model, or input/output model)	Describe how changes to components/sub-systems influence other components as well as the purpose of the system
4. Resource flows in the system (energy, matter, information)	Describe flows of matter	Describe flows of energy and/or information	Describe energy that flows and is used in the system	Describe information that is used in the system for control purposes
	Concrete	**→ → → Increased level of abstraction → → →**		

In order to get students to understand relational and extended abstract aspects of systems, technology education needs to focus more on systems thinking and general features of systems, rather than on single, isolated examples. This goes for school classrooms and well as teacher education, and concerns particularly the first and fourth of our system aspects (see Table 11.2). Regarding the system boundary and the relation to the surrounding, students could be tasked to define various types of technological systems by identifying components, sub-systems and system boundaries. Teachers could help students visualize these structural aspects of the systems, and what components and sub-systems should be included depending on how the system boundary is drawn. It is important here to discuss the fact that, for example, a car could be a component in the road transport system, while the car is also in itself a system with many components and sub-systems. Furthermore, the resource flows of the system could also be seen as an important feature of the issue of delimitation, because it is often in the interface between the system and its surrounding that flows are exchanged, for example, matter in the form of environmental pollution that several students in our study could pinpoint. However, flows of energy and information are more complex to identify, especially as in particular the flow of information also contributes to the control of the system and thereby to its delimitation (Ropohl, 1979; Svensson et al., 2012).

As regards the purpose of the system, the arduousness of thinking in terms of the flows of the system may also be a reason why the students in our study had difficulty in understanding the aim(s) of the system. One way of enhancing students' understanding of a system's purpose is to have them discuss the more general purposes of technology, for instance, for *transformation*, *storage*, *transportation* and *control*, as these purposes have evolved historically (cf. Ropohl, 1979; van Wyk, 1984). Finally, we want to propose four distinct pedagogies for teaching about technological systems that address all of our four system aspects:

1. *Interface pedagogy*: Starting with the interface between the supposed system and the human beings using it. By starting, for instance, with the toilet seat, you move the students towards the other important components and the wholeness of either the sewer system or the freshwater system, depending on the direction.
2. *Holistic pedagogy*: Starting with a well-known technological system (e.g., the railway system), you move from that wholeness and successively identify important sub-systems and components, without succumbing to an overwhelming level of detail (so-called "black boxing").
3. *Historical pedagogy*: Following the historical change—forwards from a prior point in time, or backwards from now—of a well-known technological system, you can identify important structures, sub-systems and components, e.g., in the telephone system. With this method, it is also possible to identify some of the most common patterns of technological change (see chapter by Hallström and Kaijser).
4. *Design pedagogy*: All the above pedagogies are about analysing existing systems, but many curricula refer to the notion that technology education is about designing products or systems. Designing would include investigating, prototyping, and making working models of technological systems of appropriate complexity (Hallström & Klasander, 2020 p. 73–74).

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